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ROBUST PARAMETER DESIGN FOR AGENT-BASED
SIMULATION MODELS WITH APPLICATION IN A
CULTURAL GEOGRAPHY MODEL

by

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June 2010

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Robust parameter design (RPD), which has been extensively used in industrial and system design, is used in this thesis to determine where to set controllable factors to achieve the desired response in a social dynamic-driven agent-based simulation model. Specifically, this thesis focuses on the agent-based cultural geography model (CG) of the Helmand Province, Afghanistan, developed by Training and Doctrine Center Monterey. To the author's knowledge, this thesis is the first application of RPD to an irregular warfare (IW) model that incorporates social behavior and population dynamics. Robust parameter settings for CG response were identified using a four-step experimental design and analysis methodology. Results of the developed and applied analysis and robustness study revealed important insights into the CG model. In addition to the robust parameter settings suggested by the analysis, an outcome of the simulation experiments was to illustrate a path that enables military decision makers a method for investigating the population response for different courses of action within the IW theater.

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ROBUST PARAMETER DESIGN FOR AGENT-BASED SIMULATION MODELS WITH APPLICATION IN A CULTURAL GEOGRAPHY MODEL

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ABSTRACT

Robust parameter design (RPD), which has been extensively used in industrial and system design, is used in this thesis to determine where to set controllable factors to achieve the desired response in a social dynamic-driven agent-based simulation model. Specifically, this thesis focuses on the agent-based cultural geography model (CG) of the Helmand Province, Afghanistan, developed by Training and Doctrine Center Monterey. To the author's knowledge, this thesis is the first application of RPD to an irregular warfare (IW) model that incorporates social behavior and population dynamics. Robust parameter settings for CG response were identified using a four-step experimental design and analysis methodology. Results of the developed and applied analysis and robustness study revealed important insights into the CG model. In addition to the robust parameter settings suggested by the analysis, an outcome of the simulation experiments was to illustrate a path that enables military decision makers a method for investigating the population response for different courses of action within the IW theater.

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EXECUTIVE SUMMARY

This research presents a methodology for using statistical analysis techniques to study agent-based simulations with application in a cultural geography (CG) model developed by Training and Doctrine Command Analysis Center Monterey (TRAC-MTRY).

The U.S. and the Coalition Forces of the North Atlantic Treaty Organization (NATO) are facing new challenges in today's combat. The Department of Defense (DoD) declared irregular warfare (IW) as important as conventional war. Within IW, the population is the center of gravity. Therefore, it is necessary to conduct IW, such as security, stability, transition and reconstruction (SSTR) operations, along with counterinsurgency operations (COIN), targeting the effects on the populace. In order to explore the aforementioned operation effects, TRAC-MTRY developed an agent-based simulation to model the social networks of the Helmand Province, Afghanistan, in the district of Lashkar Gah (LG). This simulation models social networks and is based on populations occupation, ethnicity, religion, and gender within LG.

The simulated social network was built using subject-matter expert knowledge in conjunction with mathematical theory. The simulated agents represent the Afghani populace, with their values, beliefs and their stance on Helmand Infrastructure, Afghan governance, and their own perception on security. Within the modeled events the population entities perfom actions according to their planned behaviors to satisfy their demand on essential services such as humanitarian aid, food, clothes and water. These events represent typical actions that are likely to be conducted during the IW.

Events or actions that occur in the simulation can be classified in two categories: controllable and uncontrollable. The controllable class includes events and actions that the U.S. military and allied forces can directly impact, including, for example, International Security Assistance Force (ISAF)

operations. The uncontrollable actions are those that occur without direct military influence. Groups that carry out uncontrollable events in the simulation include Taliban, Government Islamic Republic of Afghanistan, Non-Governmental Operations and the Afghan Women. These controllable and uncontrollable events are the focus of this thesis research. Statistically designed experiments and data analysis are used to identify the impact of these two classes of events on the Afghani's perception of security in LG. Robust parameter design (RPD) is a technique used to determine where to set the controllable factors in order to mitigate the effect of the uncontrollable factors. In other words, which settings to use for both factors resulting in a robust value for the population issue stance under consideration.

The work in this thesis uses both statistical analysis and RPD to study the effect of the programmed events, such as ISAF presence patrols, on an issue stance. The research demonstrates how simulation can be used to identify courses of action in an IW environment that can be taken to improve the population perceptions on important issues such as a sense of security. These courses of action are those under consideration by current U.S. military and allied forces stationed in Afghanistan. The simulated social network illustrates that different segments of the population required different courses of action to improve the perception of security.

LIST OF ACRONYMS AND ABBREVIATIONS

ABM	Agent-based Model
AOI	Area of Interest
ANA	Afghanistan National Army
ANOVA	Analysis of Variance
ANSF	Afghanistan National Security Forces
BBN	Bayesian Belief Nets
CG	Cultural Geography
COA	Course of Action
COIN	Counterinsurgency
DES	Discrete Event Simulation
DoD	Department of Defense
DOX	Design of Experiments
GIRoA	Government of the Islamic Republic of Afghanistan
HTT	Human Terrain Team
ISAF	International Security Assistance Force
IS	Inferential Statistics
IW	Irregular Warfare
LG	Lashkar Gar
MR	Multiple Regression
NATO	North Atlantic Treaty Organization
NGO	Non-Governmental Organization
NPS	Naval Postgraduate School
OEF	Operation Enduring Freedom
PAKAF	Pakistan-Afghanistan
RPD	Robust Parameter Design
SME	Subject Matter Expert
SMA	Strategic Multi-layered Assessment
SSTR	Security, Stability, Transition and Reconstruction Operations
TPB	Theory of Planned Behavior
TRAC-MTRY	Training and Doctrine Command Analysis Center

TRADOC   Training and Doctrine Command

UN   United Nations

U.S.   United States

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Finally, I thank my wife, Ines, for her patience and understanding during the last two years of studies at NPS. She gave me all the time I needed to fulfill my time-consuming research for this thesis. Last, my little daughter Esther—she smiled no matter what drawbacks had to be mastered.

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I. INTRODUCTION

A. BACKGROUND

> People, not platforms and advanced technology, will be the key to Irregular War (IW) success. (Department of Defense [DoD], 2007)

The U.S. and the Coalition Forces of NATO are facing new challenges in today's warfare. New strategic and tactical methods during times of fighting have been dubbed irregular warfare. Strategic IW goals are focused on security, stability, transition and reconstruction (SSTR), and tactical IW plans are focused on counterinsurgency (COIN) operations. Consideration of the civilian population is the focus of every operation in IW. IW is a violent struggle among state and non-state actors for legitimacy and influence over relevant population. (DoD, 2007). Each commander in a specific area of interest (AOI) has the responsibility to evaluate the impact of his/her military action on the civilian population. This evaluation of the consequences of military combat necessitates operational decision support.

A decision tool that would allow commanders to evaluate results of military actions and to forecast the consequential behavioral responses within a specific AOI would be invaluable. Agent-based models (ABMs) that simulate social networks and interactions between individuals or groups of people can provide this type of decision support. As an example, Cultural Geography (CG) models of Iraq and Afghanistan have been developed by TRAC Monterey, with the prime goal of analyzing the impact of IW on the culture under investigation. CG models are rooted in social science.

The population in a CG model is represented by a social network in a given geographical area. CG models are based on a combination of discrete event simulation (DES) and multiple ABM with embedded Bayesian belief networks that are used to calculate (probabilistically) the impact of an event on an issue stance within the population. For example, one can use the simulation model to evaluate changes in an issue stance resulting from an increasing

number of coalition forces. The change will have a positive or negative impact on the population's perception of a particular issue stance, such as security. These changes can be used to analyze the social network and the resulting impacts that can, in turn, contribute to the decision-making process for particular courses of action in an AOI.

1. Agent-Based Models

For further understanding of the Cultural Geography model, it is essential to understand the development and the purpose of ABMs. Sanchez and Lucas (2002) defined ABM as "a simulation made up of agents, objects or entities that behave autonomously" (Sanchez & Lucas, 2002, p. 1). The agents interact in their local environment through simple internal rules for decision making, movement, and action. "Agent-based simulations are models where multiple entities sense and stochastically respond to conditions in their local environments, mimicking complex large-scale system behavior" (Sanchez & Lucas, 2002, p. 1). ABS has been successfully used to model social networks and interactions. (Sanchez & Lucas, 2002).

2. Cultural Geography Model

The CG model is a government-owned, open-source ABM that is designed to address the behavioral response of civilian populations in conflict environments (see Figure 1.). It is a reusable framework to represent a civilian population in an IW context. Cognitive modules to represent the civilian population and their implementation as social networks are incorporated in the CG model (this is discussed in further detail in Chapter II) The social structure is implemented using homophile, the process of adjudicating the effects of tactical level outcomes on population segment within the model (Alt, Jackson, Hudak, & Lieberman, 2009a).

Cultural Geography (CG) Model

The CG model is an agent-based simulation of the operational environment based on doctrine and social theory focusing on the population's evolving stance on issues and related behaviors.
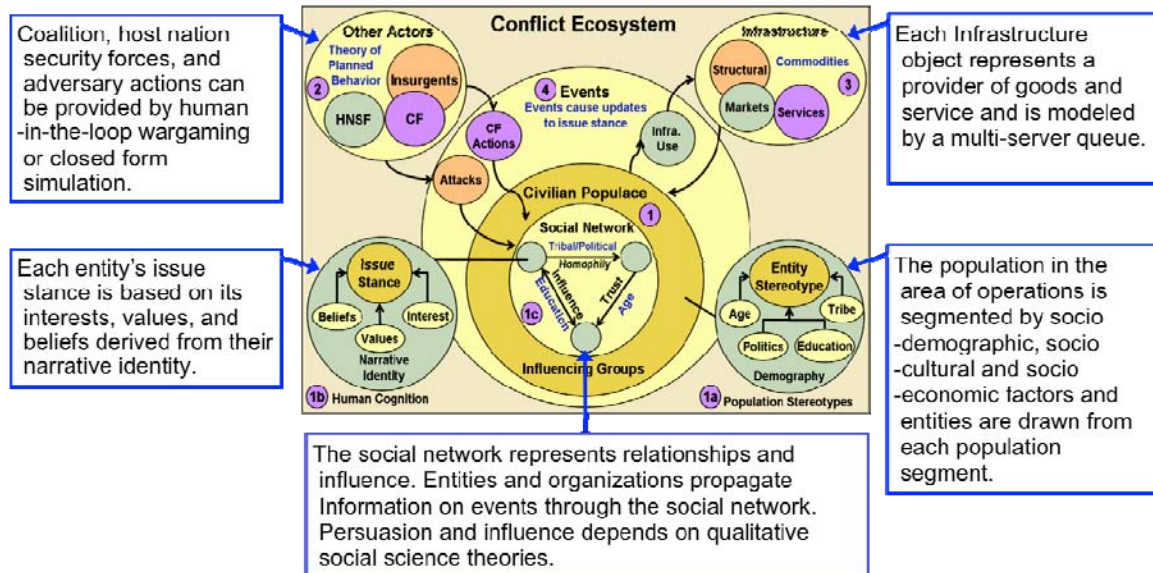
Figure 1.   Graphical Representation Of The Cultural Geography Model (From TRAC-MTRY, 2010a) (best viewed in color)

The CG model of Afghanistan was developed to give insights into the behavior of a civilian population. Currently, it is used to provide the Commander of the International Security Assistance Force Afghanistan (ISAF), General McChrystal, with important facts and meaningful insights on civilian populations and their behaviors due to ISAF and Taliban courses of action. The model captures the behavioral response of the civilian population in the environment of conflict, which can provide valuable insights regarding actions or events under consideration by the coalition forces.

The work in this thesis utilizes the CG model developed by TRAC-Monterey to study the population stances on their critical issues in the Helmand Province. The specific Helmand Province CG model is an agent-based simulation of the operational environment, based on doctrine and social theory

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within Helmand, which is designed to address the behavioral response of civilian populations specific to that region of the country, in conflict environments (Alt et al., 2009a). The model is patterned after the conflict eco-system described by Kilcullen (2007) in an attempt to capture the complexities of irregular warfare.

The Helmand CG model consists of entities (people) interacting with each other and responding to specific events. Each entity is defined by a set of demographic dimensions that collectively shape the entity's beliefs, values, interests, stances on issues (i.e., security, infrastructure, governance), and behaviors. The narrative paradigm (Fisher, 1989) is the underlying social theory upon which narrative identities are developed to form entity beliefs, values, and interests.

Within the CG modeling framework, users can schedule events that impact population beliefs and stances on critical issues. Changes in the events will manifest themselves as changes in the output of the simulation model through implementation of algorithms based on a Bayesian network. Two examples of scheduled events are (1) insurgents killing a community leader or (2) a Non-Governmental Organization (NGO) providing services. Population behaviors, such as acquiring essential services, may also impact beliefs and issue stances. Finally, population belief may be impacted through communication channels in a social network. The CG model supports representation of a social network by applying concepts of propinquity (physical proximity) and homophile (tendency to associate with those of similar interests). Specifically, when an entity's belief changes, the entity attempts to communicate the result to other entities within a pre-defined physical distance with similar interests. If communication is successful, the receiver's beliefs are impacted accordingly.

B. OBJECTIVES

1. Problem Statement

The purpose of this thesis is to provide a framework to conduct appropriate experiment design and analysis techniques, which can be applied to ABM such as Cultural Geography model from the Training and Doctrine Center, Monterey (TRAC-MTRY). Specifically, this thesis seeks to present a methodology for conducting robust parameter design (RPD) analysis of an ABM that incorporates doctrine and social theory.

2. Research Questions

The purpose of this thesis is to study RPD methods for agent-based modeling ABM. The CG model of the Helmand Province, district Lashkar Gar (LG) in Afghanistan, is used to test the RPD methodology experimental design techniques that are developed for the analysis of social networks. This effort creates mathematical models that quantify the impact of different strategies (operation types and amount) taken by coalition forces.

The use and development of methodology for RPD to analyze and evaluate courses of action to enforce stability and security in the AOI yield insights about social network behavior under the circumstances of IW and aid decision makers in the AOI by assisting in evaluating alternative courses of action.

The research answers the following questions:

- How can RPD be applied to an ABM?
- What methodology should be used to apply RPD to IW models?

RPD is used to answer questions about how to set controllable factors to a specific value in order to minimize the inpact of uncontrollable factors. Identification of factors that have the biggest impact on changes in the social

network is done using RPD. This is necessary to understand modeled behavior and ultimately use the results to influence or to help guide decision-making efforts to break up the pro-Taliban network.

C.   NATURE OF IRREGULAR WARFARE

This thesis is focused on gaining insights from ABM depicting military operations for a social standpoint. Irregular Warfare, Security, Stability, Transition and Reconstruction Operations and COIN operations are important terms for the reader to learn. A clear understanding of how the terms are used is necessary to understand the material contained in the thesis.

1.   Irregular Warfare

Irregular warfare is defined as a violent struggle among state and non-state actors for legitimacy and influence over the relevant populations. IW favors indirect and asymmetric approaches, though it may employ the full range of military and other capabilities, in order to erode an adversary's power, influence and will. It is inherently a protracted struggle that will test the resolve of our Nation and our strategic partners. (DoD, 2006, p. xi)

The DoD stated, "IW is as strategically important as traditional (conventional) warfare" (2008, p. 2). Current forces in theater like Afghanistan have to deal with counterinsurgency, counterterrorism, and stability operations.

The focus of its operations—a relevant population—and strategic purpose-to gain or maintain control or influence over, and the support of that relevant population through political, psychological, and economic methods. Warfare that has the population as its "focus of operations" requires a different mindset and different capabilities than warfare that focuses on defeating an adversary militarily. (DoD, 2007).

Figure 2 depicts the DoD representation of IW that focuses on the population and their government.
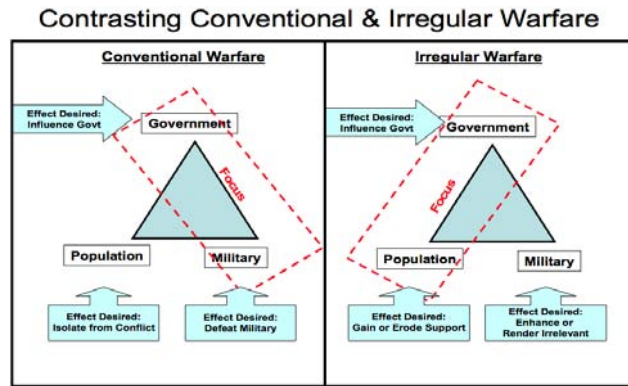
Figure 2.   Contrasting Conventional And Irregular Warfare (From DoD, 2007), (best viewed in color)

2.   Security, Stability, Transition and Reconstruction Operations

…stability operations is defined as an overarching term encompassing various military missions, tasks, and activities conducted outside the United States in coordination with other instruments of national power to maintain or reestablish a safe and secure environment, provide essential governmental services, emergency infrastructure reconstruction, and humanitarian relief. (DoD, 2009)

Furthermore, stability operations are a core element of the U.S. military and the operational backbone of the National Atlantic Treaty Organisation (NATO) and United Nations (UN) lead operations.

These operations require the following U.S. military capabilities:

- "Establish civil security and civil control.
- Restore or provide essential services.
- Repair critical infrastructure.
- Provide humanitarian assistance." (DoD, 2009)

3.   Counterinsurgency Operations

COIN operations are tied with stability operations, foreign internal defense and counter irregular threats.

The current Department of Defense definition of counterinsurgency reads as: "Those military, paramilitary, economic, psychological, and civic actions taken by a government to defeat insurgency" (DoD, 2001).

4. Regional Research Focus

The thesis research narrows the focus further by focusing on the district of Lashkar Gah (LG) within the Helmand Province. LG was chosen as the focus district within the Helmand Province for several reasons. The highest population density within Helmand Province is the LG district, with 125,000 residents. The mix of different ethic groups and tribes, in conjunction with the large number of residents in a relatively small area, results in an urban area that is known for its lack of stability and security (GALLUP, 2010).

Additionally, LG remains a critical focus for security efforts. Insurgent activity and influence by former government officials, commanders, and narcotics traffickers has made LG a prime target for destabilizing activities (Johnson, 2009).

GALLUP developed a model (GLASS) to provide means to asses the potential civil unrest within the population, without to rely on official or government statistics. GLASS is based on five statistically validated factors, basic needs, living conditions, economics, government confidence, and safety/ security. For each of the factors weights are assigned through regression analysis (GALLUP, 2010).

The Gallup GLASS model (Figure 3) based on 2009 data classifies LG as "unstable" mainly as a result of problems regarding safety and security. Confidence in local police is universally low, people's basic needs are not being sufficiently met, and living conditions result in dissatisfaction. In particular, although most households have access to water, a substantial number have experienced hunger in the past 12 months, and people are dissatisfied with trash pickup and access to electricity. LG residents are more positive, however, regarding economics and governance. Satisfaction levels with standards of living

and the job market are both strong, and satisfaction with the military is very high. Additionally, satisfaction is relatively high regarding local and national leadership. There are, however, concerns regarding the judicial system (TRAC MTRY, 2010b).

STABILITY	Unstable (red)
Basic Needs	(yellow)
Living Conditions	(yellow)
Economics	(green)
Government Confidence	(green)
Safety/ Security	Local Police (red)

Figure 3.   GLASS Model For LG District (After GALLUP, 2010) (best viewed in color)

The next two subsections give more information about the Helmand Province and LG, respectively.

a.   Helmand Province

Helmand Province, one of the 34 Afghanistan provinces, has a population of 1,441,769 residents. With 22,619 square miles, it is the largest opium production region, producing 90 percent of the world's demand—revenues from which are used to finance the Taliban forces (TRAC MTRY, 2010b).

The Province is recognized as the violent province within Afghanistan (Cordesman, 2009). The violence is caused by the Taliban-driven insurgent attacks on Afghanistan National Security Force (ANSF), Afghanistan National Army (ANA), NGO and ISAF. The attacks are almost seasonal in accordance to the religious calendar. Attacks are also most likely to happen during the warmer months and nighttime hours, and during the poppy harvest and the related ISAF opium eradication operations (Cordesman, 2009).

b.   District of Lashkar Gah

Summarized from TRAC MTRY Pakistan-Afghanistan information set, is LG situated between the Helmand and Arghandab Rivers. LG was known as the "heart of the enemy system" in Helmand in 2007 and 2008, when it was the target of repeated Taliban attempts to overtake the city. It is a major population center, with 125,000 residents, including as many as 33,000 internally displaced people. It has an infrastructure and industrial base that is relatively well developed in comparison to Helmand's other population centers (as cited in TRAC MTRY, 2010c). As a result, its capital, LG City, is currently home to Helmand's provincial government, and it hosts the governor's mansion, the headquarters of the Afghan Army and Police, the British-led Provincial Reconstruction Team, and the United Kingdom's Task Force Helmand.

LG City, which was constructed by American engineers in the 1950s and features blocks linked by wide dirt roads, has remained relatively stable. It has decent access to water and roads, including a modern highway linking LG with Kandahar City (as cited in TRAC MTRY, 2010b). Moreover, construction is underway on a new substation to provide electricity from the Kajaki Dam to additional city residents (as cited in TRAC MTRY, 2010b). In addition to having the most modern amenities of Helmand, LG residents are also the most optimistic regarding their standard of living: 57 percent believe it is improving (as cited in TRAC MTRY, 2010b).

Agriculture is the district's main source of income, with farms concentrated in the north and western edges of district along the Helmand River Valley. Despite the large numbers engaged in agriculture and the district's lush growing conditions, most farmers grow poppy and import 90 percent of their produce from Pakistan (as cited in TRAC MTRY, 2010b). Moreover, notwithstanding its relative prosperity, more than half of LG residents have not had enough money to buy enough food for themselves their families in the past 12 months. This is higher than almost all other districts polled in Helmand and is perhaps related to the district's reliance on importation (Gallup, 2009). Locally,

people are concerned most with the security of their family/tribe (a first priority of 34 percent of respondents) and unemployment (19 percent). People in LG are most dissatisfied with trash collection (72 percent dissatisfied), housing availability (61 percent), and roads (61 percent).

The information about the population of LG was used to model the cultural geography of Helmand Province. The next chapter describes how the aforementioned information is condensed into the CG model and describes important terms used in the model.

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II. MODEL DESCRIPTION

A. CULTURAL MODEL BACKGROUND

The CG model version 0.6.2 is used in this thesis. TRAC-MTRY developed this model to support the Pakistan-Afghanistan (PAKAF) strategic multi-layered assessment (SMA). CG is a discrete-event, agent-based, stochastic model. It is implemented using Java SimKit 1.3.7 as a simulation language. The current version of CG is a prototype, but has been successfully used in several studies for May Shan of Iraq and Helmand Province for the ongoing operation in Operation Enduring Freedom (OEF). The subsequent paragraphs provide an overview of the model to explain the development of methodology used for analysis of the CG model.

The multi-layered agent system is summarized as "consisting of the environment, agents, objects, and a collection of operations that can be executed by agents and rules governing operations within the environment" (TRAC-MTRY, 2009, p. 1).

1. Model Description

"The CG model is an ABM of the operational environment based on doctrine and social theory designed to address the behavioral response of civilian populations in conflict environments" (Alt et al., 2009b). The model is patterned after the conflict eco-system described by Kilcullen (2007) in an attempt to capture the complexities of irregular warfare.

The CG model consists of entities (people) interacting with each other and responding to specific events. Each entity is defined by a set of demographic dimensions that collectively shape the entity's beliefs, values, interests, stances on issues, and behaviors. The narrative paradigm is the underlying social theory upon which narrative identities are developed to form entity beliefs, values, and interests.

The CG model enables the user to schedule events that **impact population beliefs and stances** on critical issues through implementation of Bayesian networks for issues. Parent nodes of the issue networks are the beliefs and interests of target population groups, derived from their narrative identities. The end nodes of the issue networks are the entity's issue stance. An example of a scheduled event may be insurgents killing a community leader or a NGO providing medical care.

Figure 4 displays a possible belief node for a generic stereotype and its beliefs and behaviors. Population behaviors may also impact belief nodes, and thus end node issue stances.
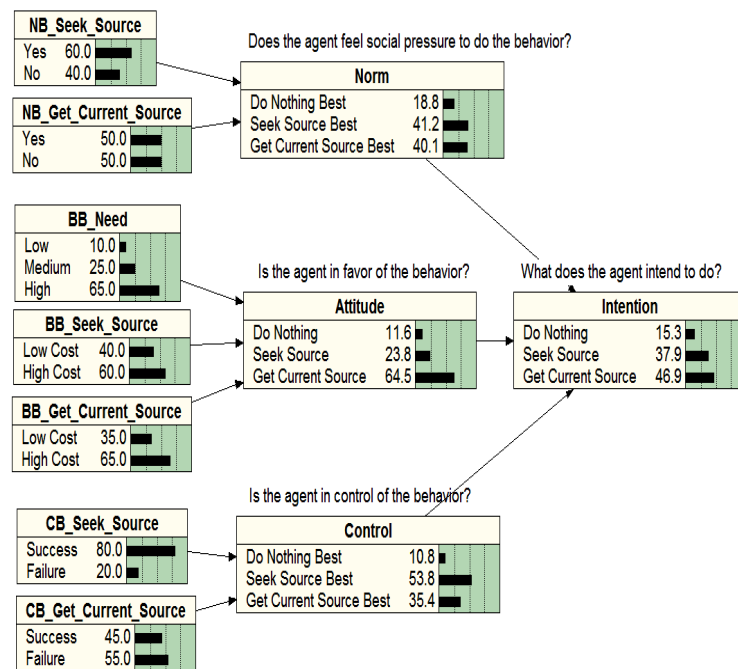
Figure 4.   Bayesian Belief Net Based On The TPB (From TRAC-MTRY, 2010a)

Population behaviors are modeled in CG through Bayesian networks using the Theory of Planned Behavior (TPB) (Figure 4). After Ajzen (2006), the TPB accounts for an entity's perceived attitude, norm, and control regarding a specific behavior.

Belief nodes may also be impacted through communication channels in a social network. The CG model supports representation of a social network by applying concepts of propinquity (physical proximity) and homophile (tendency to associate with those of similar interests). Specifically, when an entity's belief nodes change position, the entity attempts to communicate the result to other entities within a pre-defined physical distance that possess similar interests. If communication is successful, the receiver's beliefs are impacted accordingly.

B. MODEL DEVELOPMENT

The purpose of the model development is to define the population and the essential services within the Helmand Province by developing the data. The produced model resolution is gained by researching multiple resources and harvesting data from a variety of sources including firsthand information from Human Terrain Teams (HTT) deployed in that region of concern, Afghanistan Subject Matter Experts (SMEs), results from the polling and surveys from GALLUP Incooperation, New York (for further information access www.GALLUP.com), and open sources from agencies like DoD, government agencies, universities and news organizations.

The emphasis of the data development heavily relies on the SME. This ongoing process of readjusting the model with SME opinions will ensure the quality of the model during the model building process and will validate (face validation) of the model output.

1. Entity Development for LG Population

The entity development denotes the second step of modeling. Entities represent the population, and the population is a mix of several different socio-demographic groups. Since each population dimension maintains its own stance on security, governance, infrastructure, beliefs, values, and interests, it is important to describe the process of deriving the entities in detail.

a. *Demographic Dimensions and Groups*

The Helmand population entities are modeled by taking its inhabitants and grouping them into five major demographic dimensions and thirteen population groups, as shown in Figure 5. A possible entity could be: Inherited, Pro-Government, Rural Fundamentalist, Military-Age Male. This very distinct description of an entity is a stereotype that is used to name the entities within the model.

Dimension	Family Status	Tribal Affiliation	Disposition	Political Affiliation	Age
Population Groups	Inherited ("Son of")	Pro-Government (Alizai)	Rural	Fundamentalist	Military Age Male
	Achieved (Politics / Wealth)	Marginalized / Violent (Noorzai / Ishaqzai)	Urban	Moderate	Spin Giri ("White Beards"/Elders)
	Unemployed / Poor	Passive (Barakzai / Alakozai)		Progressive / Secular	

Figure 5.   Demographic Dimension And Groups (From TRAC-MTRY, 2010a)

In accordance with Figure 5, a brief description of the demographic dimensions will follow. For more detailed insights, refer to the TRAC-MTRY technical report from 2010.

- The **family status** is captured by three different groups:
    - *Inherited*: son of an elder family member whose family is respected or has religious title, or businessmen rich from poppy cultivation or trade.
    - *Achieved*: Status comes from the formal position or being a military commander or member of the Afghan parliament.
    - *Poor/Unemployed*: 40 percent of the 25 million Afghan people are without work.
- Tribe affiliation by:
    - Pro-Government (Alizai): Is the largest population Pashtun group in Helmand. They are present in government, as district chiefs and administrators.

- *Marginalized/Violent* (Noorzai/Ishaqzai): The Noorzai group is strong, connected with narcotics cultivation and trade. They are the tribe that is most connected to the Taliban. The latter was marginalized in the post-Taliban governments until 2001.

- *Passive* (Barakzai/Alakozai): Johnson describes the Barakzai as a tribe that is trusted by the Karzai government, better educated, and holding government positions (Johnson, 2009). Johnson also states that the Alakozai tribe accepts the Taliban in their vicinity without allowing operations within their territory.

- **Disposition** of population. The population distribution is either rural or urban. This distinction is made to model the essential services. About 94 percent of the populace is settled in the rural terrain where agriculture is the major source of income. An ongoing migration to urban areas is driven by better job opportunities and the fact that a better infrastructure is found in those areas.

  - *Rural:* The majority (94 percent) of the Helmand population lives in the agricultural districts in small villages. Their income is dominated by farm work and the seasonal cultivation of poppies.

  - *Urban:* The smaller portion of the population lives in the urban areas, with income mainly dominated by trade of goods and smaller businesses.

- **Political Affiliation** can be broken down into three subgroups:

  - **Fundamentalists** believe in the Islamic state and the implementation of the Islamic law (Shari'ah). They are pro-Taliban and they oppose the Karzai government. They believe that foreign forces should leave Afghanistan. Women are viewed as property.

  - **Moderates** are the traditionalists of the Afghan populace. The Islamic state and the Islamic law is what they believe as best for their government system. With that, they are connected to Taliban. Women's rights receive mixed reviews.

  - **Progressive/Secular** views the government and Islam as separate. As new democratists, they oppose radical Islam and accept the government. They believe women have the same rights and should have the same education as men.

- **Age** is divided in two groups:

  - *Military Age males* are considered the 4.5 million males in the traditional fighting age from 15 to 40 years, with a 500,000 males reaching that age per year. Another 7.5 million are the under the age of 15.

  - *Spin Giri* are over 40 years of age and considered the elders. They inherit the status within an elite family. Furthermore, they are the leaders within villages and communities in both rural and urban areas.

b. *Population Narrative Identities*

Population stances on issues like governance, infrastructure, and security are linked to the demographic dimensions. This link is established by considering the narrative identities. TRAC-MTRY resumed the description from Fischer with

> …narratives are stories through which beliefs, values, and interests are expressed and absorbed by members of society. A collective set of narratives represents a group's identity, referred to as a narrative identity. The narrative identity expresses the values and character of a group, and provides insight to a group's beliefs and intentions (Fisher, 1989). Knowledge of a population's narrative identity enhances understanding of society's core values and beliefs, which is essential to successful COIN and stability operations (TRAC-MTRY, 2010a, p.10).

From the evaluated narratives, it is possible to "...extract beliefs, values, and interests that align with the three issues under study. The beliefs and interests form the conditions for modeling issue stances" (TRAC-MTRY, 2010a, p. 69). The discussed values and beliefs of the population groups were grouped together, as shown in Figure 6. It is noteworthy to point out that the table was built to show the SME.

Demographic Group	Beliefs and Interests
Inherited	1. Tolerates illicit commerce (opium trade). (GI) 2. Government should provide infrastructure. (IG) 3. Accepts United States [US]/ISAF intervention. (GI) 4. Tolerates illicit commerce (opium trade). (GI) 5. Recognizes government authority. (G) 6. Supports Taliban reconciliation program. (G) 7. Supports Taliban and its ideology. (G)
Achieved	1. Tolerates illicit commerce (opium trade). (GI) 2. Government should provide infrastructure. (IG) 3. Recognizes government authority. (G) 4. Accepts US/ISAF intervention. (GI) 5. Pakistan ties OK for commerce. (I)
Unemployed / Poor	1. Tolerates illicit commerce (opium trade). (GI) 2. Accepts US/ISAF intervention. (GI) 3. Willing to accept illegal / illicit job. (I) 4. Actively supports the insurgency. (GI) 5. Pakistan ties OK for commerce. (I) 6. Government is ineffective / irrelevant. (G) 7. Supports Taliban and its ideology. (G)
Pro-Government	1. Tolerates illicit commerce (opium trade). (SG) 2. Helmand/Afghanistan is not secure. (S) 3. Pakistan ties OK for commerce. (S) 4. Accepts US/ISAF intervention. (SG)
Marginalized / Violent	1. Advocates violence in pursuit of goals. (S) 2. Tolerates illicit commerce (opium trade). (SG) 3. Distrusts ISAF forces. (SG) 4. Actively supports the insurgency. (SG) 5. Pakistan ties OK for commerce. (S) 6. Supports Taliban and its ideology. (SG) 7. Helmand/Afghanistan is not secure. (S)
Passive	1. Tolerates illicit commerce (opium trade). (SG) 2. Helmand/Afghanistan is not secure. (S) 3. Accepts US/ISAF intervention. (SG) 4. Supports Taliban reconciliation program. (SG) 5. Pakistan ties OK for commerce. (S)
Rural	1. Advocates violence in pursuit of goals. (S) 2. Tolerates illicit commerce (opium trade). (SI) 3. Distrusts ISAF forces. (SI) 4. Helmand/Afghanistan is not secure. (S) 5. Actively supports the insurgency. (IS) 6. Pakistan ties OK for commerce. (SI) 7. Supports Taliban and its ideology. (S) 8. Government should provide infrastructure. (I) 9. Willing to accept illegal / illicit job. (I) 10. Views urban residents as corrupt / untrustworthy. (GI)
Urban	1. Helmand/Afghanistan is not secure. (S) 2. Accepts US/ISAF intervention. (IS) 3. Supports Taliban reconciliation program. (S) 4. Tolerates illicit commerce (opium trade). (SI) 5. Pakistan ties OK for commerce. (SI) 6. Government should provide infrastructure. (I)

Demographic Group	Beliefs and Interests
	7. Willing to accept illegal / illicit job. (I) 8. Views rural residents as naive / traditional / trustworthy. (GI)
Fundamentalist	1. Outsiders not welcome. (S) 2. Advocates violence in pursuit of goals. (S) 3. Tolerates illicit commerce (opium trade). (SG) 4. Distrusts ISAF forces. (SG) 5. Actively supports the insurgency. (SG) 6. Supports Taliban and its ideology. (SG) 7. Government is ineffective / irrelevant. (G)
Moderate	1. Outsiders not welcome. (S) 2. Tolerates illicit commerce (opium trade). (SG) 3. Helmand/Afghanistan is not secure. (S) 4. Accepts US/ISAF intervention. (SG) 5. Supports Taliban reconciliation program. (SG) 6. Recognizes government authority. (G)
Secular	1. Tolerates illicit commerce (opium trade). (SG) 2. Helmand/Afghanistan is not secure. (S) 3. Accepts US/ISAF intervention. (SG) 4. Supports Taliban reconciliation program. (SG) 5. Recognizes government authority. (G)
Military Aged Male	1. Advocates violence in pursuit of goals. (S) 2. Tolerates illicit commerce (opium trade). (SGI) 3. Distrusts ISAF forces. (SGI) 4. Helmand/Afghanistan is not secure. (S) 5. Actively supports the insurgency. (SGI) 6. Pakistan ties OK for commerce. (SI) 7. Supports Taliban and its ideology. (S) 8. ANSF not a viable employment option. (S) 9. Government should provide infrastructure. (IG) 10. Willing to accept illegal / illicit job. (I) 11. Government is ineffective / irrelevant. (G)
Spin Giri ("White Beards" / Elders)	1. Helmand/Afghanistan is not secure. (S) 2. Accepts US/ISAF intervention. (SGI) 3. Supports Taliban reconciliation program. (SG) 4. Government should provide infrastructure. (IG) 5. Accepts US/ISAF intervention. (SGI) 6. Recognizes government authority. (G)
Legend: Letters next to the beliefs indicate that the belief is aligned with that issue. S=Security, I=Infrastructure, G=Governance.	

Figure 6.   Beliefs and Interest by Population Group (TRAC-MTRY, 2010a)

c.   Population Stereotypes

The Combination of all possible demographic groups with each demographic dimension results in 108 theoretically possible stereotypes. In reality, there are some combinations for stereotypes that do not exist. An

example for a practical non-existing stereotype is one who has achieved wealth, has marginalized political views, lives in an urban area, holds fundamentalist views, and is a male of military age. Accounting for all practical non-existing stereotypes results in 52 practical possible stereotypes.

One element of the stereotypes is their communication within their social network, which is based on their beliefs, values, stances on issues, and behaviors. It is crucial for the process of analyzing a social network to analyze the communication behavior and the amount of the entities given the occurrence of a special event. Furthermore, software components (listeners) were implemented to track and save the communication between each entity and the overall amount of communication in the timeframe under investigation (182 simulation days).

d.   Population Behaviors

To model the population behavior, TRAC-MTRY developed the Theory of Planned Behavior (TPB) and Bayesian Belief Nets (BBN), which are based on social science and the methodology to simulate human behavior using two steps (Alt et al., 2009a).

The CG model uses the TPB and BBN to account for population behaviors. After Ajzen (2006) the TPB accounts for the perceived attitude of an entity toward his behavior, subjective norm, and perceived behavioral control regarding a specific behavior. Furthermore, the TPB follows a specific structure. The following (Figure 4) structure represents the format in which the intention an entity seeks is satisfied. This intention building is based on BBNs. "These are probabilistic frameworks that provide consistent and coherent evidence reasoning with uncertain information" (Pew & Mavor, 1998, p. 186). Furthermore,

> The BBN follow the Bayes' theorem, which allows one to update the likelihood that situation S is true after observing a situation-related event E. If one assumes that situation S has prior likelihood Pr(S) of being true (that is, prior to the observation of E), and one then observes a related event E, one can compute the posterior likelihood of the situation S, Pr(S|E), directly by means of Bayes' theorem:

$$\Pr(S \mid E) = \frac{\Pr(E \mid S)\Pr(S)}{\Pr(E)}$$

Where Pr(E|S) is the conditional probability of E given S, which is assumed known through an understanding of situation-event causality (Pew & Mavor, 1998, p. 186).

To account for population behaviors, the TPB is used first to encode the attitude, norm, and control on Identity before trying to obtain infrastructure resources. Within the model, there are separate identical networks for every infrastructure resource. The way in which the agents are modeled within CG is complex in architecture. By using the displayed structure in Figure 5, it is possible to determine if an agent makes the decision to acquire essential services, not acquire them, or seeks them from a different resource. The starting attitude toward a behavior has been determined through SME verification. During the simulation process, the agent TPB will change based on the success or failure of acquiring the resource. In the case of successfully acquiring a service like potable water, the entities' beliefs are impacted positively towards the issue stances on governance and infrastructure.
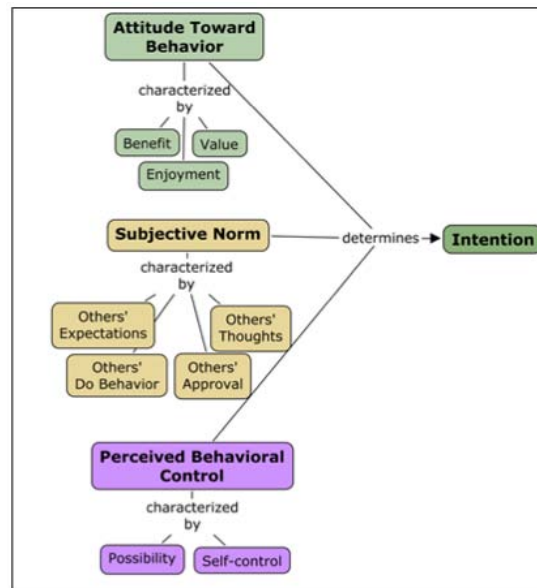
Figure 7.   Structure Of TPB (From TRAC-MTRY, 2010a)

Next, the BBN will be called to simulate the population cognition to ascertain the reactions of the group to scripted events. The social science involved will account for the psychology of human behavior. Figure 8 displays the BBN on issue stance of security. The beliefs on the left are connected to the issue stance security to the right. The relation between the beliefs and the issue stances is learned from the Gallup data and does not change (static) during simulation time.
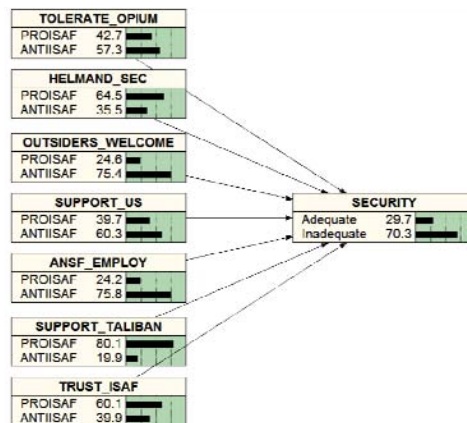
Figure 8.   Bayesian Belief Network Representation On Issue Stance Security
(From TRAC-MTRY, 2010a)

e.   *Social Network*

SMEs assessed interaction and communications patterns among the thirteen population groups and other actors. This created an asymmetric matrix of the likelihood of communication in terms of their similarity among social factors. The matrix is the medium to define the strength of social ties between the thirteen population groups and five other actors (see Figure 5, p. 16). Figure 9 displays the values from one to nine. The value of one stands for least likely to communicate and nine is most likely. The matrix is asymmetric; the order of sender and receiver is significant. For example, an Inherited (I) communicates to an Achieved (A) is six, which indicates the likelihood of their intercommunication.

The social ties in conjunction with the entities' proximities will give the overall likelihood that entities communicate with each other and therefore pass information through the social network.

Figure 9.   Sender/Receiver Matrix (portion)(From TRAC-MTRY, 2010a) (best viewed in color)

C.   SCENARIO DEVELOPMENT

The scenario development was built on possible operations of the actors (ISAF, Taliban, NGOs, Government of the Islamic Republic of Afghanistan [GiRoA]) actions within the district LG. The scenarios will reveal insights into the issue stance security of the population due to the many possible courses of acrion (COA) of the mentioned actors. The simulated scenarios show the effectiveness of the actors' actions.

1.   Background

According to the Technical Report (TRAC-MTRY, 2010a) the population entities perform different actions within the scenarios. They are consuming essential goods and services, whereby they, based on TPB, seek the services or not. They either succeed or not in acquiring these services and react to their success or failure. They communicate this reaction via the social network

Furthermore, the consumption of essential goods and services depends on the stochastic event and is tailored to every individual stereotype. The processes of seeking services or goods are stochastic events driven by the likelihood of the intention node (refer to section b. Population Behavior) of the TPB.

Server operating times, capacity, transfer rates, and extent of server damage are the four infrastructure sub-model impacting parameters. The reactions to either success or failure of acquiring essential services are deterministic events resulting in case files that impact the entity's TPB and its beliefs. The communication of this success or failure with other actors depends on proximity to other entities and a stochastic process resulting from strength of social ties. Whereas social ties represent the likelihood that two entities communicate with each other due to their social propinquity.

2. Infrastructure and Essential Services

In order for an entity to seek or not seek an essential service, CG has implemented the infrastructure of the Helmand Province and the population's needs. Furthermore, the starting conditions of TPB for the population to seek essential services where implemented and the Helmand capacities were modeled using multi-server queues. The essential services and their providers are shown below.

Essential Service	Provider
Potable Water	GIRoA
Farm Supplies	GIRoA
Farm Supplies	Taliban
Medical	GIRoA
Medical	ISAF
Medical	NGO
Legal	GIRoA
Legal	Taliban
Irrigation Water	GIRoA
Transportation	GIRoA
Electricity	GIRoA
Employment	GIRoA
Employment	Taliban

Figure 10.   Essential Services And Provider (From TRAC-MTRY, 2010a)

a.   *Agent Distribution*

Fifty-two different types of entities are represented by 200 agents distributed across 10 zones within LG, relative to the population estimate of the dimensions.

3.   Other Actors and Behaviors/Events

The actors and the possible events will be described in detail throughout this chapter. It is important to mention the fact that the stated events are real in nature and currently in use during the ISAF efforts in the Helmand Province. TRAC-MTRY took five actors into consideration for further study of event impact on the developed social network. The actors are ISAF, GiRoA, NGO, Taliban, and Women. In order to evaluate the factors within the CG model, it is necessary to describe the actors that will initialize the researched events. The CG scenario is developed to incorporate all possible major actors within the Helmand Province.

- ISAF: Executes lethal and non-lethal events, which directly impact the population's beliefs and the issue stance security.

- Taliban: The Taliban is the primary insurgent in Helmand. Their actions/ operations will directly impact the infrastructure and the governance issues. The Taliban will execute lethal and non-lethal (recruiting and information operations) events for the civilian population and ISAF.

- GiRoA: The Governance provides essential services for the population. Their absence will negatively impact the issue stance on governance.

- NGOs: The amount of NGOs is restricted. NGOs provide essential services.

- Mothers: To observe the female influence on the Afghan family i.e., the magnitude of supporting recruiting through the Taliban or Afghanistan National Security Forces.

The five actors and the events representing their behavior within the model combine to create 14 factors for the model.

Actor	Behavior/Event
ISAF	Initiates "presence patrols" twice daily.
ISAF	Conducts a raid and takes some of your neighbors into custody.
ISAF	Cordons off your street and searches for suspects.
ISAF	Meets with your leaders and shuras.
ISAF	Eradicates opium from the fields.
Taliban	Sends threatening letters to your house at night.
Taliban	Plants an IED that explodes and kills your neighbors.
Taliban	Provides you and your neighbors with food, water and clothes.
Taliban	Kills a community leader that you admire in your town.
Taliban	Convinces some of your neighbors to join their forces.
GIROA	Provides you and your neighbors with food and water and clothes.
NGO	Provides you and your neighbors with food and water and clothes.
Mother	Tells you she would be proud of you if you joined the Taliban.
Mother	Tells you she would be proud of you if you joined ANSF forces.

Figure 11.   Other Actors And Their Behaviors/ Events (After TRAC-MTRY, 2010a)

4.   Event Frequency

The event frequency requires description for the development of the scenario and the building of the experimental design (Chapter IV). The frequency in which an event can occur is naturally upper bounded due to the capacities of forces in theatre, the amount of available resources of essential services, and how often people communicate with each other. The following table considers the upper and lower bounds of event frequencies for 14 events.

Actor	Behavior/Event	Low Frequency	High Frequency
ISAF	Initiates "presence patrols" twice daily.	14 per week	42 per week
ISAF	Conducts a raid and takes some of your neighbors into custody.	1 per week	7 per week
ISAF	Cordons off your street and searches for suspects.	1 per week	7 per week
ISAF	Meets with your leaders and shuras.	1 per week	7 per week
ISAF	Eradicates opium from the fields.	1 per week	7 per week
Taliban	Sends threatening letters to your house at night.	1 per week	7 per week
Taliban	Plants an IED that explodes and kills your neighbors.	1 per week	7 per week
Taliban	Provides you and your neighbors with food, water and clothes.	1 per week	7 per week
Taliban	Kills a community leader that you admire in your town.	1 per week	7 per week
Taliban	Convinces some of your neighbors to join their forces.	1 per week	7 per week
GIROA	Provides you and your neighbors with food and water and clothes.	1 per week	7 per week
NGO	Provides you and your neighbors with food and water and clothes.	1 per week	7 per week
Mother	Tells you she would be proud of you if you joined the Taliban.	1 per week	7 per week
Mother	Tells you she would be proud of you if you joined ANSF forces.	1 per week	7 per week

Table 1.   Frequency of Other Actor Events (After TRAC-MTRY, 2010a)

D.   BASELINE SCENARIO

The baseline scenario will cover the 14 events described in the last paragraph. They were executed with their low frequencies for six months (182 simulation days). The limitation for the baseline scenario was that actors were not adapted to existing conditions. Since entities are dynamic in their decision-making process about whether to seek an essential service (or not), or seek an

essential service from another source, it was necessary to deny the decision-making process to investigate the baseline scenario run results for validity.

The focus of Chapter II was to identify and describe agent-based models and their practical use within the Cultural Geography model from TRAC-MTRY. Further detailed explanations of specific termini used within this study were provided to understand the context of the study objective at hand. Moreover, crucial insights into the nature of IW in the context of the Afghan population and the possible COA for the military leader in the ISAF theatre were given, to understand the development of the social network representing the Afghan population. Regarding the research question in Chapter I, the following chapter provides insights and expands the theory of RPD and its use to analyze the aforementioned actors' events.

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III.   ROBUST PARAMETER DESIGN

A.   INTRODUCTION

There are multiple statistical ways to design new products and processes or to improve existing ones. One way to analyze them is through the process of robust parameter design, which this research uses.

The use of the RPD ensures that the mean of the output response (e.g., social network stability) will be within the aimed level and that the variability around that level is efficiently small (Montgomery, 2009). Moreover, the implementation of RPD will allow the observation of the controllable and uncontrollable factors in the model and their contribution to the CG model response to isolate crucial factors, which have impact on the variance of stability within the social network.

RPD is embedded as one essential component in the design of experiments (DOX). The RPD process, developed by Ginichi Taguchi, is described as (Montgomery, 1999):

- Making the process insensitive to environmental factors or other factors that are difficult to control,
- making products insensitive to variation transmitted from components, and
- finding levels of the process variables that force the mean to a desired value, while simultaneously reducing variability around this value.

RPD is a method that focuses on the right choice of parameters within an observed system. These parameters and their levels can be easily manipulated by the system designer to gain robustness in the system. Robustness is considered insensitivity to changes in the range of the uncontrollable variables. Montgomery stated in his paper, *Experimental Design for Product and Process Design and Development* (1999, p. 159), the following objectives of an experiment:

- to determine which variables are the most influential on the response(s),

- to determine where to set the influential xs so that the response(s) are almost always near the desired target value,

- to determine where to set the influential xs so that the variability in the response(s) is small or

- to determine where to set the influential xs so that the effects of the uncontrollable variables on the response(s) are small.

Figure 12 demonstrates a generalization of a model with input parameters and the response.
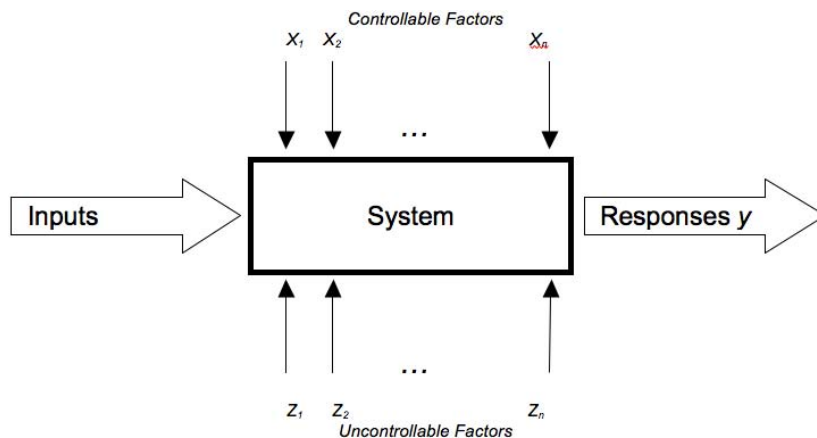
Figure 12.   General Model Of A System

RPD, as illustrated, has been extensively used for industrial experiments, industrial design, and system design. There is very little use of these types of RPD methods in the context of social experimentation and design. To the author's knowledge, this thesis is the first application of RPD to an IW model that incorporates social behavior and population dynamics.

The application of RPD within IW will be conducted on the CG ABS model of the LG district, Helmand Province, Afghanistan. The controllable and uncontrollable factors shown in Figure 13 represent the factors represented in the CG model. The resulting output from the model will enable the user (military decision maker) to determine the settings for the controllable factors with the goal to both find the setting of the controllable factors that produce the most desirable response in the civilian population and mitigate the undesirable impact of the

uncontrollable factors on the response. In addition to the robust parameter settings suggested by the analysis, an expected outcome of the simulation experiments will be to enable the military decision maker with a path to investigate the population response for different COA within the theatre of IW.

Inputs	Controllable Factors	Uncontrollable Factors	Output
Social Network	ISAF Initiates "presence patrols" twice daily.	Taliban Sends threatening letters to your house at night.	Perception of the populations stance on security
Bayesian Belief Net	ISAF Conducts a raid and takes some of your neighbors into custody	Taliban Plants an IED that explodes and kills your neighbors.	
Entities	ISAF Cordons off your street and searches for suspects.	Taliban Provides you and your neighbors food, water and clothes.	
Infrastructure Commodities	ISAF Meets with your leaders and shuras.	Taliban Kills a community leader that you admire in your town.	
	ISAF Eradicates opium from the fields.	Taliban Convinces some of your neighbors to join their forces.	
		GIRoA provides essential services	
		NGO provides essential services	
		Women communicate join the Taliban	
		Women communicate join the ANSF	

Figure 13.   Matrix of CG Model Factors, Inputs And Output

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IV. EXPERIMENTAL DESIGN

A. MEASURE OF EFFECTIVENESS

To determine the impact of operations on the populace over time, the CG agent-based model was used to provide a temporal analysis of the population issue stances and the factors that cause change. Different actors and the range of possible actions they can take impacts the population of Helmand Province. Within the CG, the population was modeled with their beliefs, behaviors, and stances regarding three issues: governance, infrastructure, and security.

The measures of effectiveness (MOE) for the research is the CG simulation response **security.** It is the perception of the population on security and is, in the context of this research, defined as followed.

1. Definition of Security

In order to be compliant with the modeler's definition of terms within the model, the following definition for security is used.

Security is defined whether the population perceives security to be adequate or inadequate. According to numerous research and polling data, security and safety concerns are generally some of the primary causes of instability and are usually focused on the population's confidence on the local police and security forces effectiveness. Insurgent groups pose the greatest threat to security in the form of terrorizing the population, planting improvised explosive devices (IEDs), and deliberate attacks against security forces.

The Model output is best described as one that questions the population about their perception of security after each event. For example, if the Taliban send more threatening night letters to the population, how does this cause a change in the perception of security? The change to the aforementioned baseline scenario is then given in magnitude and value as model output.

B. DESIGN OF EXPERIMENTS

Within the research, experimental design techniques are used to leverage simulation model results, the selection of different ranges for input parameters, controllable, and uncontrollable parameters, which will impact the simulation model output. Experimental Design specifies the factor settings for each experimental trial. These settings are best viewed in a matrix. Figure 14 displays the DOE matrix, showing the columns as the levels for every factor within each experiment. The matrix rows stand for a specific combination of factor levels; therefore, every row represents a design point.

1. Experimental Factors

Two types of experimental factors are present: controllable and uncontrollable. The controllable factors are also called decision factors. The decision factors are the ones that can be modified by the experimenter. In this case, they represent the actions taken by the ISAF. Noise factors are treated as the actions taken by Taliban, NGOs, GiRoA, and Women. These are actions taken by actors who cannot be controlled. One might argue that in the real world we have control over the actions taken by NGOs and GiRoA; however, in this research they are treated as noise because the research is investigating the population issue stance on security with the focus on ISAF possible COA to boost security and mitigate the noise's effects.

	ISAF_PresencePatrol	ISAF_Raid	ISAF_C&S	ISAF_KLE	ISAF_OpiumEradication	Tal_NightLetters	Tal_IED	Tal_ProvideServices	Tal_KillCommunityLeader	Tal_Recruit	GIROA_ProvideServices	NGO_ProvideHumanitarianAid	Wom_CommunicateJoinTal	Wom_CommunicateJoinANSF
low level	14	1	1	1	1	1	1	1	1	1	1	1	1	1
high level	42	7	7	7	7	7	7	7	7	7	7	7	7	7
DP														
1	14	1	1	7	1	1	7	7	1	1	7	1	7	7
2	14	1	7	1	7	1	7	1	7	7	1	7	7	7
3	14	1	7	1	7	7	7	1	1	1	7	1	1	1
4	14	1	7	7	1	7	1	7	7	7	1	1	1	7
7	14	7	1	1	1	1	7	7	7	1	1	7	1	1
6	14	7	1	1	7	7	1	7	1	7	7	7	7	7
7	14	7	1	7	7	7	1	1	7	1	1	1	7	1
8	14	7	7	7	1	1	1	1	1	7	7	7	1	1
9	42	1	1	1	1	1	1	1	1	7	1	1	7	1
10	42	1	1	7	7	1	1	1	7	1	7	7	1	7
11	42	1	1	7	7	7	7	7	1	7	1	7	1	1
12	42	1	7	1	1	7	1	7	7	1	7	7	7	1
13	42	7	1	1	1	7	7	1	7	7	7	7	1	7
14	42	7	7	1	7	1	1	7	1	1	1	1	1	7
17	42	7	7	7	1	7	7	1	1	1	1	7	7	7
16	42	7	7	7	7	1	7	7	7	7	7	1	7	1

Figure 14.   DOE Matrix

2.   Design Methodology

The goal of this thesis is to illustrate a methodology used to find robust settings for an agent-based simulation model. Design of experiments and response surface methodology are used to facilitate that goal. The experimental design (screening design) and analysis process taken was an iterative approach. Figure 15 illustrates the steps taken to find the robust parameter settings.
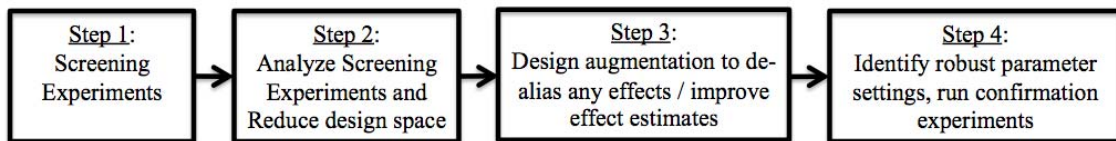
Figure 15.   Experimental Design Methodology

The first step in the process was to reduce the dimensionality of the design space by identifying the factors that significantly impact the response of interest. The sparsity of effects principle suggests that only a small portion of the factors will account for most of the variability in the response. There are 14 factors in this experiment. With 14 potential main effects, there are 91 possible

two factor interactions (2FI), summing to a total of 105 potential significant terms. In order to reduce this, a screening experiment is used to find the significant effects.

An irregular 2_{III}^{14-10} fractional factorial was used for the screening experiment. The design is irregular because it does not use one of the traditional generators to create the design. The generator used for this design is one that does not produce any full confounding relationships. This screening design is a traditional two level design for which each of the factors is set at only two levels (low and high). The low and high levels of the design correspond to the low and high frequency of events. This screening design will give insights in the main effects of the factors on the response, security. Furthermore, it was used to find robust settings for the response. Since the aforementioned factors have two levels, the assumption is that the response is linear over the range of the chosen factor levels (Montgomery, 2009). The design matrix, which presents the levels to set each factor for every experiment in the design, is shown in Figure 14.

After the screening design has run to completion, step 2 in the design methodology phase (see Figure 15), regression analysis is used to determine the impact of the main effects on the perception of security. In a resolution III design, only the main effects are estimable. If the model fitting results in a reduced design, through determination of insignificant effects, some two-factor interactions (2FI) may be studied. It is important to realize that those two factor interactions are aliased with other two factor interactions and potentially other main effects as well. If the analysis indicates that a 2FI is significant, its true effect must be carefully considered. As a follow-up, additional experiments must be conducted to de-alias terms. As a result of using an irregular design resolution III design, none of the 2FIs will be completely confounded with any other main effects or 2FIs. The partial confounding allows easier resolution of effects, but still requires additional experimentation.

The alias relationship between the significant interactions and the main effects can be calculated through linear algebra. We can define X_1 as the matrix containing all of the main effects (note: this is our original design matrix as shown in Figure 14). Then we can define X_2 as a matrix containing additional variable not accounted for in the original experimental design setup. We define X_2 as a matrix with the three interaction terms. Then A, the alias matrix can be calculated by the following equation

$$A = (X_1'X_1)^{-1} X_1'X_2$$

Using this relationship, we can show the aliases between any significant 2FI's and main effects that are present. If there are alias relationships present, further experiments are necessary to remove these aliases.

Step 3 of the experimental design process (Figure 15) includes the designing an execution of additional experiments that are anticipated after the analysis in Step 2. The experimental design created in this step is aimed to de-aliase any effects and also to generate experiments that improves the estimates of the factors identified as significant. The design choice for this step is discussed in Chapter V along with the analysis.

Step 4 of this experimental design methodology is used to identify the robust settings for the significant controllable factors as given by the results. This is done by finding the settings of these factors such that the adverse impact of the uncontrollable factors is minimized.

C.   SCENARIO EXECUTION

The scenario modeled is a self-terminating simulation. The simulation in this case is carried out to simulate a time period of 182 (real world) days. Within this time period, the aforementioned entities consume and seek services according to their TPB, until other actors' events are executed. There are a fixed number (defined by the level settings of the factors) of events for each variation of the scenario; therefore, the number results from the calculated design points (each design point represents an experiment) for the chosen design.

The termination of the simulation is caused by the completion of all scheduled events. Over the simulation time of 182 days, each experiment is run 14 times, with a different random seed for each variation of the scenario. This enables statistically independent runs/observations of the response variable security over the simulation time scheduled.

V. DATA ANALYSIS

This chapter focuses on the application of RPD to gain insights of specific events on the populace security issues stance and the significant factors for the LG district, Helmand Province Afghanistan. Specifically, the means and procedures of the analysis are described.

The in-depth analysis, using different analysis methods demonstrates how to achieve a robust response (security) against different courses of actions executed by the agents in the simulation.

A. TOOLS AND TECHNIQUES

The experimental design and analysis process in this thesis is general. After the simulation run, the data is collected, cleaned and analyzed. There are several software packages used to perform the cleaning and analysis of data. Their description follows. After the software is presented, the general techniques of analysis are given.

1. Software Tools

Two analysis tools were used. First, an in house data-scrubbing tool used for cleaning the results is described. Second, the commercial statistical software package used is presented.

The simulation model used in this thesis was developed by TRAC-MTRY. In addition to developing the simulation model used, TRAC-MTRY also developed Java script useful for cleaning the model output data set. The tool can be used to condense the data and perform tasks such as organizing the output by demographic dimension, population groups and by the district LG.

For the analysis of the data set, the commercial software JMP 8 Statistical Discovery Software from SAS institute was used. JMP provides the user with a large variety of statistical tools to explore the data set. Using the JMP application to represent the data set, the graph building tools provided by JMP give several

ways to "see" the data and gives meaningful visual insights in the coherence and relation of the data. For further information refer to the JMP hompage (www.jmp.com).

2. Analysis Techniques

The analysis techniques used in this thesis were intended to provide answers to the research questions. Deciding what statistical and mathematical analysis techniques are most suitable required finding which methods provides information on revealing the settings for controllable factors that make the response robust against likely settings of the noise (uncontrollable factors).

Statistical design and analysis techniques often include the use of both descriptive and inferential statistics. The graphical analysis used for the descriptive statistical analysis of the agent-based simulation presented in this thesis turned out to be invaluable, because it provided insights that were unexpected.

Inferential statistical techniques used in this thesis included analysis of variance (ANOVA) tables, stepwise regression, least squares model fitting, and individual hypothesis testing. These tools are used to investigate the statistical importance of factors under consideration. The analysis of factors and their importance and contribution to the model are imperative for a robustness study.

B. RESULTS

The analysis was carried out to answer the research questions from Chapter I.B. The following results are the major results and findings of a more detailed analysis, but are not displayed in their entirety.

1. Graphical Analysis

During this study, one of the most useful graphical techniques was a series of box plots for the response variable that were organized based on the

specific agents in the model. Layers of box plots give indication about the differences in responses within the various agent subgroups.

Figure 16 shows graphical displays of the population stereotypes in their fragments over the 10 zones modeled in LG. The x-axis in Figure 16 shows the mean of the security response. The left and right y-axes in Figure 16 show the three different family statuses and the three political affiliations. Many of the zones have the same patterns because they contain similar stereotypes within each zone. Notice that for Zones 1–10 (above x-axis in Figure 16), the fundamentalist (F) Political affiliation have three main distinctions in average security response for the inherited (I), achieved (A), and poor/unemployed (Un) family status types. The I family status appears to have a higher average security response, but also largest variance when compared with A and Un. The Un types of groups appear to uniformly have the lowest response with the lowest variability. This is incredibly insightful.
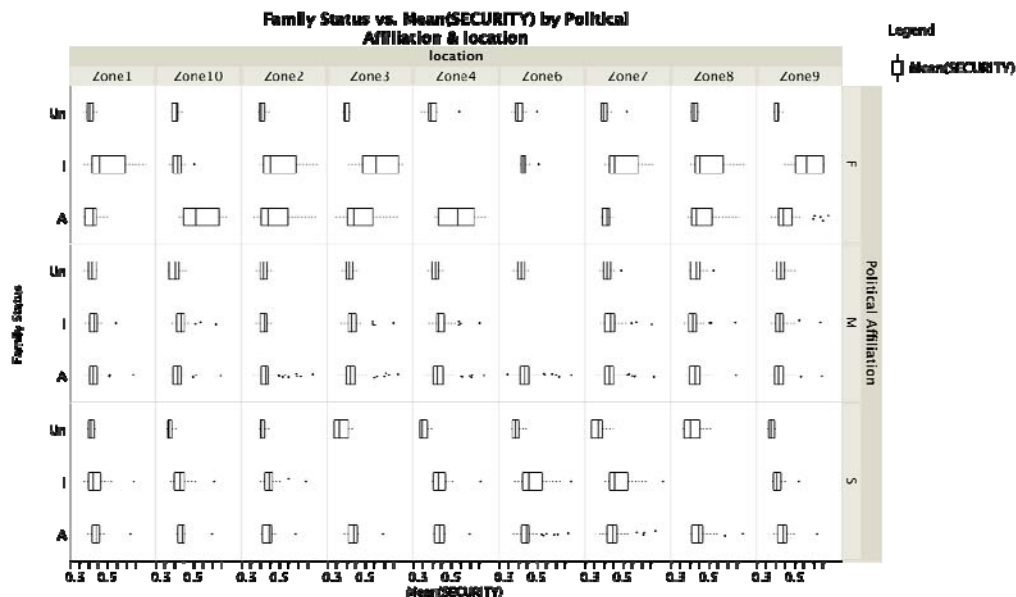

Figure 16.   Graph of Stereotypes Over LG—Zone 1 To 10

This graph suggested that it was important to perform separate statistical analyses, both descriptive and inferential, for the different stereotypes in the LG

model. In an agent-based simulation model, this finding was very useful. The findings in this thesis indicate that robustness settings should be different for the different types of agents contained in the model. The agents in this CG model are the different stereotypes within LG. For further statistical analysis in this thesis, zone 3 was chosen due to the great differences in the variances of family status in conjunction with the political affiliation of the stereotypes in that same zone as shown in Figure 17.
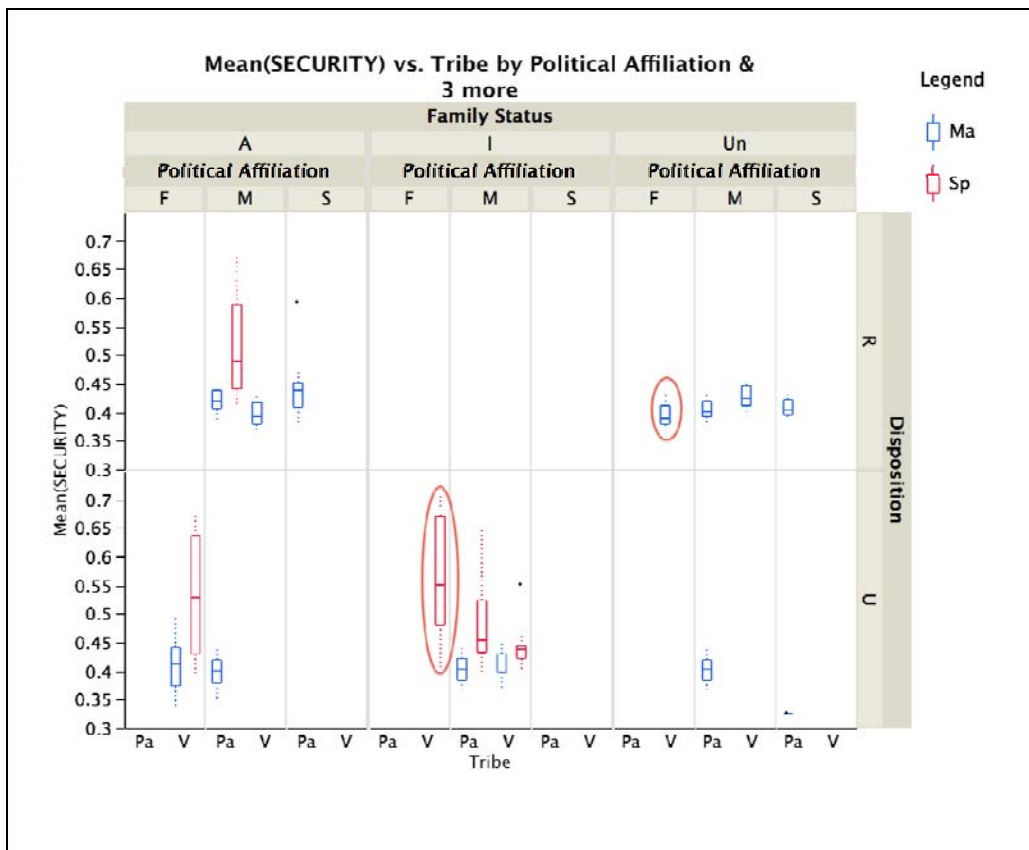
Figure 17.   JMP Graph Builder Displays Two Stereotypes Of Interest In Zone 3 (circled), (best viewed in color)

As Figure 17 displays, there are two stereotypes that are interesting to analyze. The graph shows that both are very distinct in their variability and can be seen by the related box-plot of their responses. In addition to their variability they have a very different mean of security, providing extra reason to investigate these discrepancies.

Figure 17 contains circled box-plots that are two different stereotypes. First, a stereotype in zone 3 that is an elder person of inherited family status that has violent tribal affiliation with fundamentalist political views, and is living in an urban area has visual considerable large variance in the response (stereotype one). Second, in contrast the stereotype that represents a military age male who is unemployed with violent tribal affiliation, has fundamentalist political views and lives in a rural area (stereotype two) has a visual spread in the response but in direct comparison to the elder ones, it is not as huge.

The next section presents the results from the inferential statistics and robustness analysis of the aforementioned stereotypes that will be used to show the process of the analysis and robustness study for ABM output. The graphical analysis of the data set will point the analyst to obvious disharmonized graphical patterns in the build graphs. The results of the data analysis will be used to identify significant variables. Factors that significantly impact the response will be candidate factors for robust setting. That is the values for the controllable factors that mitigate the impact of the uncontrollable factors will be identified.

2. Inferential Statistics

In this section, the use of inferential statistics (IS) is described. IS is used to make predictions for the response and draw conclusions based on the analysis of the numeric data at hand. An essential step in this process is to verify the significant factors in the context of linear regression. The multiple linear regression equation is given below (Equation 1). In this Equation, y, represents the dependent variable, security.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_1 \beta_2 x_1 x_2 + \varepsilon \qquad (1)$$

The x_j's represent the independent variables; in this case the controllable and uncontrollable factors. The β's are the partial regression coefficients and

measure the expected change in *y* per unit change in the x_j's when the remaining independent variables held constant. The error term is represented by ε and is assumed to be NID $(0,\sigma^2)$.

The subject matter experts for the CG model were fairly confident that the results of the experimental design would not be a complex model. The linear regression was assumed to be adequate. The initial multiple linear regression model assumed includes initially only main effects, but is expanded to include two factor interactions as well. The regression model above (Equation 1) shows both main effects and two factor interactions.

Multiple regression is used to answer the question of the main effects and two factor interactions that impact the perception of security. The prediction profiler, a built- in function in the JMP software, is used to visualize the results of the fitted regression model. The application of this technique is explained further in the following chapter about robustness settings.

a.   Logit Function

In order to analyze and directly compare results of responses it is necessary to standardize the factors into coded units. In Chapter II.D.4, the factor values were described. Coded units are obtained by standardizing these variables to fall between -1 and 1, which represent the low and the high value settings for the event frequencies.

In addition to transforming the factors into coded units, a transformation of the model response here Mean (Security) is carried by using the logit function. This is done because the variable security is bounded by 0 and 1 and can be viewed as a percentage that measures percent satisfaction with the security.

The fitted regression models for the LG Zone 3 and two stereotypes were fit using the transformed response (logit of mean security). This transformation is useful to stabilize the variance in that response. The function is

also functional in practice to make the distribution of the response variable closer to the normal function (Myers et al., 2009). Additionally, the transformation prevents the prediction model from creating predictions that are above one or below zero.

The logistic function displayed in Equation 3 can take a variety of inputs like values from negative infinity to positive infinity for the factor values x_j's. Equation 3 displays two factors (x_j's). However, the values of the function output *f(z)* are values between 0 and 1.

$$f(z) = \frac{1}{1 + e^{-z}}$$

with

$$z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_1 \beta_2 x_1 x_2 + \varepsilon \qquad (3)$$

The variable *z* is the total contribution of all independent variables in the model. And *f(z)* is the probability of the outcome when the independent variables are used in the formula.

The particular transformation of the model response in this research is calculated using following formula displayed in equation 4.

$$y^* = \ln\left(\frac{p}{1-p}\right)$$

where

$$p = Mean(Security) \qquad (4)$$

To transform the predicted responses back to the original units the formula in Equation 3 is used.

The fitted models for each, zone 3 and both stereotypes are illustrated below. First the results are displayed individually and then later in the chapter they are compared together in order to visualize the difference between them and tie them in the robustness study.

b. Inferential Statistics for Zone 3

Mixed stepwise regression was used to select the significant terms to use in the fitted model. All of the main effects and two factor interactions were included in the possible terms to be considered during stepwise regression. The values to enter and leave the model are set at both 0.05. Recall, the initial data is fit using only the fractional factorial design. Because the design is irregular, the stepwise regression can attempt to differentiate between significant partially aliased terms, but to truly de-confound the significant terms, additional experimentation is necessary.

Figure 18 presents JMP output from the fitted model. The fitted model contains terms selected by the stepwise regression analysis. The output shows that the model is significant (p-value < 0.05 percent) and accounts with 99.8 percent for the variability for the response Logit (security).

Summary of Fit

RSquare	0.998481
RSquare Adj	0.996203
Root Mean Square Error	0.008288
Mean of Response	−0.27066
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	0.27101350	0.030113	438.3291
Error	6	0.00041219	0.000069	Prob > F
C. Total	15	0.27142569		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	−0.270656	0.002072	−130.6	<.0001*
ISAF_C&S	0.0069475	0.002072	3.35	0.0154*
ISAF_KLE	0.0267391	0.002713	9.86	<.0001*
ISAF_OpiumEradication	−0.039521	0.002072	−19.07	<.0001*
Tal_IED	−0.043573	0.002072	−21.03	<.0001*
Tal_KillCommunityLeader	0.024324	0.002713	8.97	0.0001*
Tal_Recruit	0.0420959	0.002713	15.52	<.0001*
ISAF_PresencePatrol*NGO_ProvideHumanitarianAid	−0.061744	0.003503	−17.63	<.0001*
ISAF_KLE*NGO_ProvideHumanitarianAid	0.0126374	0.002713	4.66	0.0035*
ISAF_OpiumEradication*Wom_CommunicateJoinTal	−0.153024	0.003837	−39.88	<.0001*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio		Prob>|t|
ISAF_OpiumEradication*Wom_CommunicateJoinTal	−0.153024	0.003837	−39.88		<.0001*
Tal_IED	−0.043573	0.002072	−21.03		<.0001*
ISAF_OpiumEradication	−0.039521	0.002072	−19.07		<.0001*
ISAF_PresencePatrol*NGO_ProvideHumanitarianAid	−0.061744	0.003503	−17.63		<.0001*
Tal_Recruit	0.0420959	0.002713	15.52		<.0001*
ISAF_KLE	0.0267391	0.002713	9.86		<.0001*
Tal_KillCommunityLeader	0.024324	0.002713	8.97		0.0001*
ISAF_KLE*NGO_ProvideHumanitarianAid	0.0126374	0.002713	4.66		0.0035*
ISAF_C&S	0.0069475	0.002072	3.35		0.0154*

Figure 18.   Fitted Model For LG Zone 3

The fitted model displayed in Figure 18 contains six main effects and three interaction terms. The sorted parameter estimates within Figure 18 is organized from largest effect estimate to smallest effect estimate (magnitude). This is another way to visualize the x_j's with their contribution to the fitted multiple regression model. The bars to the left show the negative contribution of the listed factor to the model and bars to the right show the positive contribution of the listed factor to the model. We use Taliban_Improvised Explosive Device to give one explanation of a present independent factor in the regression model and what it means in respect to the multiple regression. As this factor value goes from one to seven (low to high level) occurrences per week, the resulting security change in percent is calculated by using the log odd function as shown in equation 5. It gives as result for the estimated (β) of Taliban improvised explosive device of -0.4375, a change in security of minus 35 percent.

$$\log\_odd = e^{-\beta} \qquad (5)$$

However, the statistically significant factors in the model are the Table 2 listed controllable factors: ISAF_Cordon and Search, and ISAF_Opium Eradication in conjunction with the uncontrollable factors: Taliban_Improvised Explosive Device, Taliban_Kill Community Leader, and Taliban_Recruit. These six factors have the greatest impact on the perception on security of the populace within the zone 3 of LG.

Main Effects (independent variables/ controllable and uncontrollable factors)	Interactions (Two-Factor and Two- Way)
- ISAF_Cordon & Search - ISAF_Opium Eradication - Taliban_Improvised Explosive Device - Taliban_Kill Community Leader - Taliban_Recruit	- ISAF-Presence Patrol*NGO_Provide Humanitarian Aid - ISAF_Key Leader Engagement*NGO_ Provide Humanitarian Aid - ISAF_Opium Eradication* Women Communicate Join Taliban

Table 2. Summary Of Main Effects And Interactions For MR Of Zone 3

Table 2 displays the interaction plots for all of the significant two-factor interactions in the fitted model. The steeper the line corresponding to the factor is the larger is the impact of the factor in the model. Crossed lines for the factors indicate the interaction between both. The interactions show that one action or event cannot be seen isolated from another event in context of the model response. To explain this phenomenon we use, ISAF_Presence Patrol interacts with NGO_Provide Humanitarian Aid (see box within Figure 19). When ISAF_ Presence Patrol is at its high level (+1), then there is an impact on the response it decreases when NGO_Provides Humanitarian Aid is on its high level (+1) and increases when NGO_Provides Humanitarian Aid is on its high level (+1) and ISAF_Presence Patrol is on its low level (-1). However when ISAF_Presence Patrol is on its low level (-1) and NGO_Provides Humanitarian Aid is on its high level (+1) the response increases.
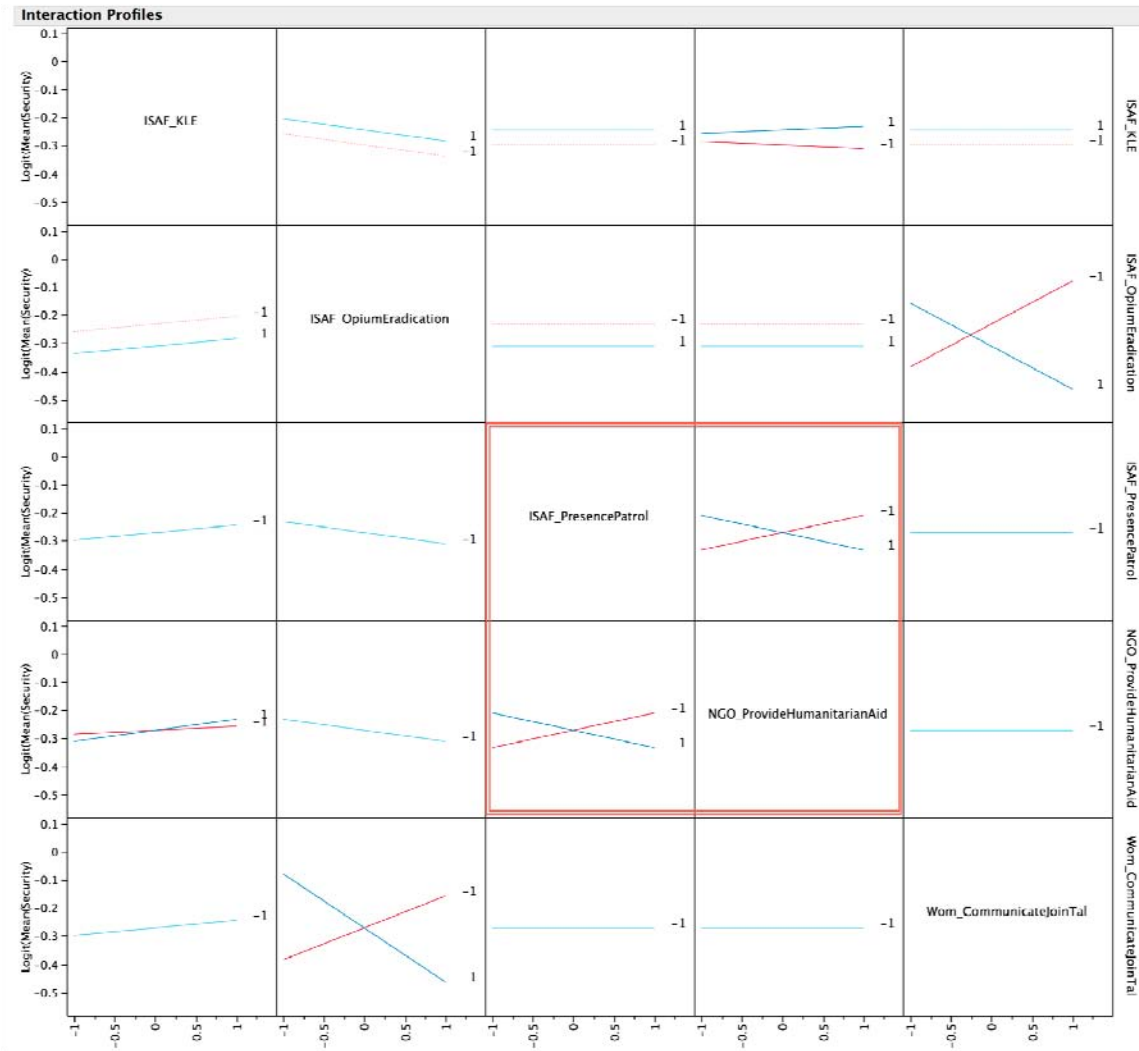
Figure 19.   JMP Interaction Plot For Zone 3 Factor Effects (best viewed in color)

c.   Inferential Statistics for Stereotype One

Stereotype one is an elder person of inherited family status that has violent tribal affiliations with fundamentalist political views and is living in an urban area. The fitted model (Figure 20) for stereotype one is significant with $p<0.05$ percent, and the variability is explained with 95 percent by the model.

Summary of Fit

RSquare	0.952766
RSquare Adj	0.929149
Root Mean Square Error	0.110011
Mean of Response	0.28241
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	2.4412285	0.488246	40.3425
Error	10	0.1210250	0.012103	Prob > F
C. Total	15	2.5622535		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2824105	0.027503	10.27	<.0001*
ISAF_PresencePatrol	0.2050643	0.033684	6.09	0.0001*
ISAF_PresencePatrol*ISAF_KLE	−0.082984	0.027503	−3.02	0.0130*
ISAF_Raid*ISAF_C&S	0.0821403	0.033684	2.44	0.0349*
ISAF_KLE*Wom_CommunicateJoinTal	−0.12354	0.027503	−4.49	0.0012*
ISAF_OpiumEradication*Wom_CommunicateJoinTal	−0.148643	0.033684	−4.41	0.0013*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio		Prob>|t|
ISAF_PresencePatrol	0.2050643	0.033684	6.09		0.0001*
ISAF_KLE*Wom_CommunicateJoinTal	−0.12354	0.027503	−4.49		0.0012*
ISAF_OpiumEradication*Wom_CommunicateJoinTal	−0.148643	0.033684	−4.41		0.0013*
ISAF_PresencePatrol*ISAF_KLE	−0.082984	0.027503	−3.02		0.0130*
ISAF_Raid*ISAF_C&S	0.0821403	0.033684	2.44		0.0349*

Figure 20.   Fitted Model For Stereotype One In LG Zone 3

In the model for all stereotypes in zone 3, six main effects and three interactions terms were significant. In contrast to this, the model for stereotype one has just one main effect, but four interaction terms as displayed in Table 3. This fact illustrates the complexity of a social network of stereotypes representing a population. It can be stated that every stereotype has to be seen and treated with very different methods to cause changes in their behavior, or in this case, in their perception of security.

Main Effects (independent variables/ controllable and uncontrollable factors)	Interactions (Two-Factor and Two-Way)
• ISAF_Presence Patrol	• ISAF-Presence Patrol*ISAF_Key Leader Engagement • ISAF_RAID*ISAF_Cordon & Search • ISAF_KLE* Women Communicate Join Taliban • ISAF_Opium Eradication* Women Communicate Join Taliban

Table 3. Summary Of Main Effects And Interactions For MR Of Stereotype One

d.   Inferential Statistics for Stereotype Two

Stereotype two is the unemployed military age male with a violent tribal affiliation, who has fundamentalist political views and lives in a rural area. Figure 21 displays the JMP output for the fitted model using the stereotype two data.

Summary of Fit

RSquare	0.955279
RSquare Adj	0.925465
Root Mean Square Error	0.0198
Mean of Response	−0.42964
Observations (or Sum Wgts)	16

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	0.07537005	0.012562	32.0414
Error	9	0.00352841	0.000392	Prob > F
C. Total	15	0.07889846		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	−0.429635	0.00495	−86.79	<.0001*
ISAF_C&S	0.0147682	0.00495	2.98	0.0154*
Tal_ProvideServices	0.0200751	0.00495	4.06	0.0029*
ISAF_Raid*ISAF_C&S	0.0323311	0.00495	6.53	0.0001*
ISAF_Raid*Wom_CommunicateJoinTal	−0.035752	0.005716	−6.25	0.0001*
ISAF_C&S*Wom_CommunicateJoinTal	−0.04551	0.00495	−9.19	<.0001*
ISAF_OpiumEradication*GIROA_ProvideServices	0.0140866	0.005716	2.46	0.0359*

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio		Prob>|t|
ISAF_C&S*Wom_CommunicateJoinTal	−0.04551	0.00495	−9.19		<.0001*
ISAF_Raid*ISAF_C&S	0.0323311	0.00495	6.53		0.0001*
ISAF_Raid*Wom_CommunicateJoinTal	−0.035752	0.005716	−6.25		0.0001*
Tal_ProvideServices	0.0200751	0.00495	4.06		0.0029*
ISAF_C&S	0.0147682	0.00495	2.98		0.0154*
ISAF_OpiumEradication*GIROA_ProvideServices	0.0140866	0.005716	2.46		0.0359*

Figure 21.   Fitted Model For Stereotype Two

The fitted model for stereotype two has two main effects and four interaction terms. Noteworthy are the factors for ISAF actions in the interaction terms. Furthermore, they can be seen as useful since they are the leverage, together with noise actions, that impact the population's stance on security. The status of the women is viewed differently by individual tribes. In this example for the interaction between ISAF_Raid with Women_Communicate Join Taliban and ISAF_Cordon and Search with Women_Communicate Join Taliban, it can be seen that the security will decrease when ISAF conducts military operations and the women urge their children to join the Taliban.

Main Effects (independent variables/ controllable and uncontrollable factors)	Interactions (Two-Factor and Two- Way)
• ISAF_Cordon & Search • ISAF_ProvidesServices	• ISAF_Raid*ISAF_Cordon & Search • ISAF_Raid*Women_Communicate Join Taliban • ISAF_Cordon & Search*Women_Communicate Join Taliban • ISAF_Opium Eradication*GIROA_Provides Services

Table 4. Summary Of Main Effects And Interactions For MR Of Stereotype Two

The summary of the inferential statistics displays the resulting main effects and interactions gained through MR to serve as an example for the different reactions of the population when opposed by military operations in their district. It reemphasizes the fact that controllable factors and uncontrollable factors present operations either by ISAF, Taliban, NGOs, GIRoA and women. In the course of the robustness study, Table 5 presents the main effects and interactions that is the leverage to either increase, decrease, or maintain the value for security.

Main Effects (independent variables/ controllable and uncontrollable factors)	Interactions (Two-Factor and Two- Way)
All of Zone 3	
• **ISAF_Cordon & Search** • ISAF_Opium Eradication • Taliban_Improvised Explosive Device • Taliban_Kill Community Leader • Taliban_Recruit	• ISAF-Presence Patrol*NGO_Provide Humanitarian Aid • ISAF_Key Leader Engagement*NGO_ Provide Humanitarian Aid • *ISAF_Opium Eradication* Women_Communicate Join Taliban*

Stereotype One	
• ISAF_Presence Patrol	• ISAF-Presence Patrol*ISAF_Key Leader Engagement
	• *ISAF_RAID*ISAF_Cordon & Search*
	• ISAF_Key Leader Engagement* Women_Communicate Join Taliban
	• ***ISAF_Opium Eradication* Women_Communicate Join Taliban***

Stereotype Two	
• **ISAF_Cordon & Search**	• *ISAF_Raid*ISAF_Cordon & Search*
• ISAF_Provides Services	• ISAF_Raid*Women_Communicate Join Taliban
	• ISAF_Cordon & Search*Women_Communicate Join Taliban
	• ISAF_Opium Eradication*GIROA_Provides Services

Table 5. Main Effects And Interactions For Zone 3, Stereotype One And Stereotype Two (best viewed in color)

The ISAF_Cordon and Search operation is notable; it is a main effect for all of zone 3 and for stereotype two (printed bold). The interpretation is that both operations will have an impact on the response in zone 3 and on stereotype two. In the question how the security can be impacted, these two main effects have high leverage; either they contribute to the model response or they do not. Which way they contribute depends on their value settings, which play a significant role in the robustness study.

The two-factor interactions ISAF_Opium Eradication and Women_Communicate Join Taliban (printed bold italic) for zone 3 and stereotype one show the complex relationship between both factors in the model. This interaction also reveals that Opium Eradication, representing a controllable factor in the model and in a real world military operation has great leverage for security in connection with the women communicating.

Last is the two-factor interaction between ISAF_Cordon and Search and ISAF_Raid (printed italic) for both stereotypes. The perception of security for both stereotypes is affected by both ISAF operations in a positive magnitude. This, in context of ISAF operations, makes sense, since the response of both stereotypes to ISAF operations is positive.

Concluding the inferential statistics, it is obvious that multiple regression (MR) contributes significantly to the process of finding the main effects and interactions and identifying their contribution to the model response. To answer the question of how can the security positively be impacted, one must know their settings and their magnitude within the regression model for the stereotype under investigation. Even if one district like zone 3 has to be investigated, it is important to know the implications of the stereotypes in that zone. As seen in Table 5, not every ISAF operation will impact the population response in the same manner.

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VI. ROBUSTNESS STUDY

This chapter addresses how the response of the zone 3 analyses can be utilized to improve the population's perspective of security and (if possible) also utilized to determine settings that are robust against uncontrollable factor values. The presence of interactions between uncontrollable and controllable factors is a prerequisite for identifying robust settings, which creates the "if possible" caveat. The impact of uncontrollable factors on the response, in this case security perception, can only be mitigated by controllable factors if there is significant interaction between controllable and uncontrollable factors. A significant interaction refers to statistical significance, meaning the unknown regression coefficient associated with the effect must be significantly different from zero.

The main effects and interactions, as noted in the inferential statistics section of Chapter V, are used to set the security response to highest possible level. This could be achieved in the classical approach using the MR. Setting the values for the x_j's (p. 45 Equation 1) representing ISAF to that level increases the response the most, and setting the x_j's representing the uncontrollable factors to that level decreases the response the most.

The prediction profiler, which is a built in function in JMP, can be very useful in this context. After the JMP help menu, the prediction profiler displays the prediction of each of the MR present x_j's. As seen in Figure 22, the dotted line for each x-value shows the current value for that x. The factor values can be changed in the boundaries of low and high values for the events respectively by sliding the vertical red dotted line to the new current value.

The black lines within the plots show how the predicted value changes when the current value of an individual x variable is changed. The 95 percent confidence interval for the predicted values is shown by a dotted curve surrounding the prediction trace (for continuous variables) or an error bar (for categorical variables).
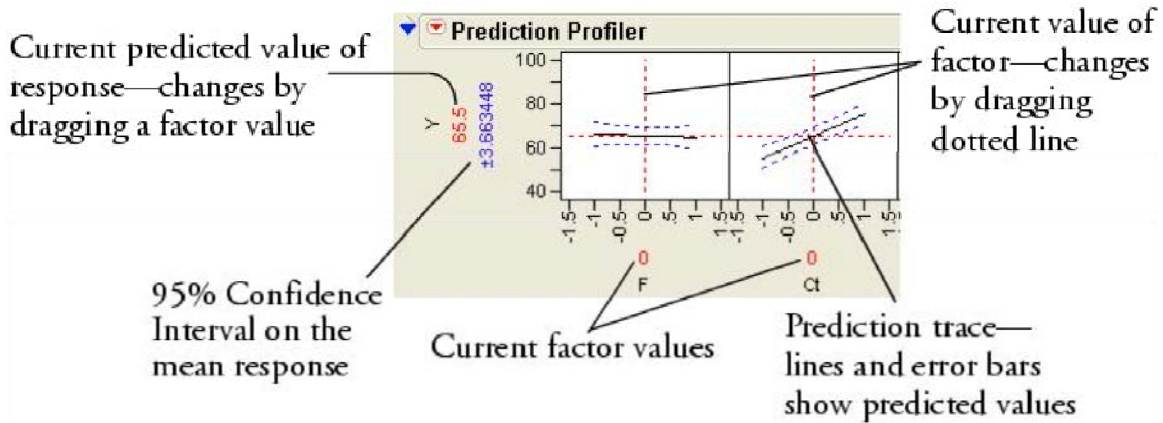
Figure 22.   JMP Prediction Profiler (JMP 8 Help Menu) (best viewed in color)

1.   Robustness for All Zone 3 Stereotypes

In order to make the response security robust against the uncontrollable factor settings and to obtain the highest response, we first vary the controllable factor settings. (This is similar to the courses of action that can be taken by the ISAF to strengthen the perception of security within theatre in Afghanistan). Specifically we set ISAF_ Cordon and Search, ISAF_ Key Leader Engagement to the high level and ISAF_Opium Eradication to the low level. Whereas ISAF_Presence Patrol is left unchanged, since the slope of the prediction trace is equal to zero.

Second, the uncontrollable factors values are set to the highest settings, which infer that their impact on security is as negative as possible. This procedure is shown in Figure 23. All uncontrollable factors are set to the high settings, thereby interpreting that they occur more often (Refer to Chapter. II.D.4.).
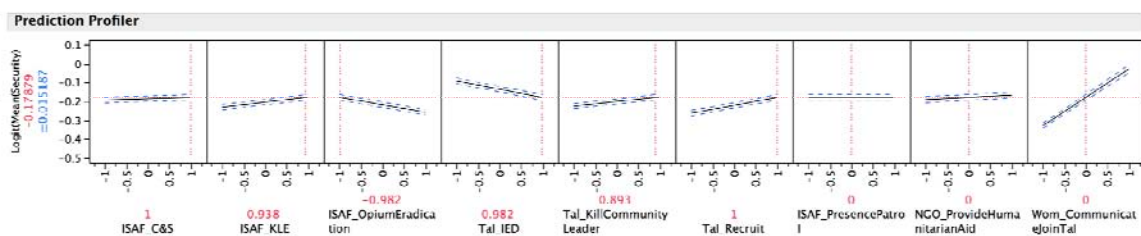

Figure 23.   Prediction Profiler For High Values For Noise Factors

The insights of this robustness study are twofold. First, increasing the occurrence of Taliban_Recruit and Taliban_Kill Community Leader has a positive impact on the response. The second is the presence of interaction between ISAF_Opium Eradication and Women_Communicate Join Taliban. The analysis of the present model revealed that increasing the frequency of Women_Communicate Join Taliban demands the decrease of ISAF_Opium Eradication in order to reinforce the perception on security.

Therefore, to make the response robust against any levels of uncontrollable factors, ISAF needs to increase ISAF_Cordon and Search, ISAF_Key Leader Engagement, and reduce the frequency of ISAF_Opium Eradication.

2.   Robustness for Zone 3 Stereotype One

Under the circumstances of less present main effects (refer to Table 5) the robustness of the stereotype one issue stance on security is complex, due to the effect of the numerous interactions present. Furthermore the COA for ISAF operations are more greatly interwoven with the actions taken by the Women in zone 3. Surprisingly there are no effects from the Taliban, NGOs, or even GiROA. It could be concluded, that the stereotype one perception of security is positively impacted by the actions taken by ISAF forces in the region of zone 3. Figure 20 displays the prediction profiler for stereotype one where ISAF_Presence Patrol, ISAF_Key Leader Engagement, ISAF_Raid, ISAF_Cordonand Search, and ISAF_Opium Eradication are set to their high levels to obtain the highest possible value for the response.
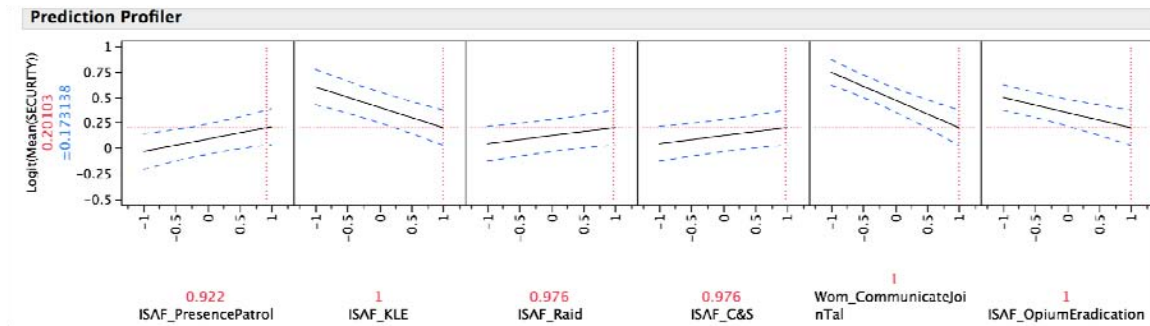
Figure 24.   Prediction Profiler for Stereotype One

Setting the value for ISAF_Key Leader Engagement to high produces a remarkable loss in the perception of security setting the same value to low produces a much higher value for security.

Moreover, it is obvious and expected that when Women are communicating to join the Taliban, the perception of security decreases. In contrast, displayed in Figure 24, the ISAF_Key Leader Engagement and ISAF_Opium Eradication are counterproductive to security, while ISAF_Raids and ISAF_Cordon and Search support security.

3.   Robustness for Zone 3 Stereotype Two

To make the responses as robust as possible against all possible uncontrollable factor value settings, we set the controllable factors ISAF_Cordon and Search, ISAF_Raid, and ISAF_Opium Eradication to their highest value settings.

From Figure 25, it is obvious that the communication from the women to join the Taliban is the major factor that impacts the response negatively. The communicating women interact with ISAF_Raids and ISAF_Cordon and Search (refer to Table 5) and have a negative impact on the overall response.
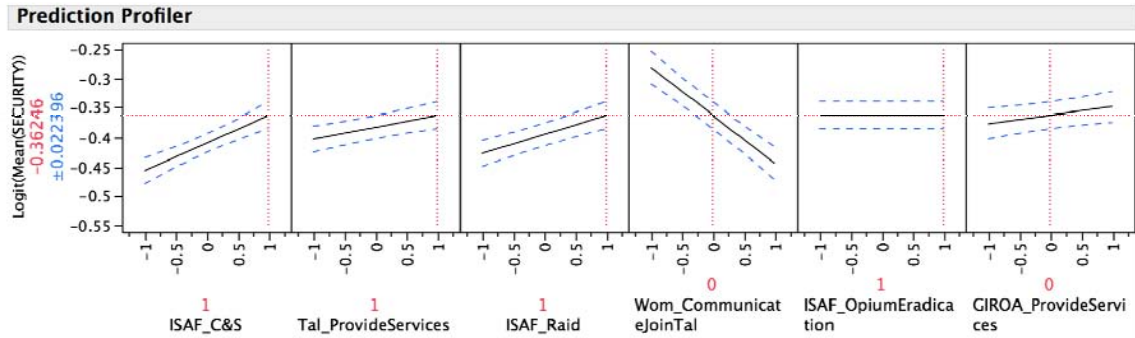
Figure 25. Prediction Profiler For Stereotype Two

The robustness study revealed the complexity of social network behavior under the circumstances of IW. Making the response robust against uncontrollable factor settings is complicated since every stereotype reacts in a different way to controllable factors. The JMP Prediction Profiler in conjunction with inferential statistics is the major contributor to the process of evaluating robust settings for the response security.

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VII. CONCLUSIONS

A. SUMMARY

The purpose of this study was to develop a methodology for the use of robust parameter design for agent-based models with application to a cultural geography model. The focus of this research was based on the need to identify and research methods to determine how ABMs could be analyzed and what methodology should be used to find robust settings for the model response. Therefore this thesis developed a four-step methodology to find robust settings for an agent based model. Furthermore, the robustness study was illustrated by exploring a specific zone in LG and two population stereotypes.

The work in this thesis uses both statistical analysis and RPD to study the effect of the programmed events, such as ISAF presence patrols, on an issue stance. The research demonstrates how simulation can be used to identify courses of action in an IW environment, which can be taken to improve the population's perceptions of important issues such as their sense of security. These courses of action are under consideration by current U.S. military and allied forces stationed in Afghanistan. The simulated social network illustrates that different segments of the population requires different courses of action to improve the populace opinion of security.

This research is based on TRAC-MTRY developed ABM, CG. The model is a prototype; however, it was used in the past to research the cultural environment and the impact of military operations on the population of Iraq. Presently it is being used in the coalition effort of NATO in the theatre of ISAF in Afghanistan. CG lets one analyze the effects of possible operations on the population. Furthermore, it evaluates the impact on the population's issue stances on governance, infrastructure, and security, which was in the focus of

this study. The operations within this analysis were based on actual studies done by TRAC-MTRY to provide COM PAKAF with detailed insights into the Helmand Province populace.

To verify the possible operations, initially a screening design was used to study the effect of 14 events similar to military operations on security. A 2_{III}^{14-10} fractional factorial design of experiments was used with follow on experiments necessary to de-alias any significant factors. These designs illustrate the main effects of the controllable and uncontrollable factors on the response, security. The analysis of the model output was conducted with JMP 8 statistical software. Graphical and classical analysis was performed to gain insights into the model output.

In order to develop a methodology for robustness studies for ABMs JMP 8 was used first to explore the data set graphically. These graphs were used to initially display causal relationship between events and the population. In addition, traditional multiple regression was utilized to identify the statistically practical significant main effects and two-way interactions of the model. Again using JMP 8 build- in functions, in connection with MR, are the major leverage within robustness studies in this research.

B.   SIGNIFICANT CONTRIBUTIONS

The use and the development of methodology for RPD to analyze and evaluate courses of action to secure and to enforce stability and security in the AOI will yield insights about social network behavior under the circumstances of IW and will aid decision makers in the AOI by assisting in evaluating alternative courses of action. The methodology to apply robustness studies to ABM provides TRAC-MTRY with further research of modeled regions within Afghanistan and contributes to the coalition forces efforts in context of ISAF.

C. FUTURE RESEARCH

The effort of this thesis was to develop a methodology for robustness studies for ABMs. However, in the course of this research the analysis of the experiment's design revealed the need for further investigation of the design space, the research of specific modeled demographic groups, and their influence on social network modeled. The analysis of the district LG showed, for example, that elder males in urban areas cause a larger variability on the response, security than other demographic groups. Future study should address the following:

- Study demographic groups in urban areas to obtain more information of the impact of military operations on the perception of security of the populace.

- Expand the developed four-step methodology for analysis of COA to address issues of risk and cost analysis in order to inform and guide decision makers towards operation outcomes.

- Explore other different DOEs—D-optimality,

- Perform cost versus outcome analysis using CG to provide Civilian Affairs Agents with insights in their area of operation efforts in context with financial limitations.

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